Materials in Design Engineering

FORMERLY MATERIALS & METHODS

SELECTION & USE OF METALS, NONMETALLICS, FORMS, FINISHES

Joining and Fastening Plastics | Manual No. 145

Porous Metal Filter Media

How Radiation Affects Organic Coatings

Complete Contents—page 1

UARY, 1958

Materials in Design Engineering

formerly Materials & Methods

Selection & use of metals, nonmetallics, forms, finishes

JANUARY 1958 VOL. 47, NO. 1

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COVER BY HARRY & MARION ZELENKO

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What's new IN MATERIALS

...AT A GLANCE

STRONGER MAGNESIUM FORGINGS THAN PRESENTLY AVAILABLE are said to result from solution heat treating for 2 hr at 930 F followed by conventional aging. According to the producer, ". . . the treatment hikes short-time elevated temperature properties of ZK60A magnesium forgings and improves their resistance to creep by as much as 400% at 300 F." Greatest use of the treatment will probably be for large magnesium aircraft forgings; the treatment has been found to increase the tensile yield strength of a large aircraft wheel forging from 29,000 psi to 44,000 psi.

A REINFORCED PLASTIC WITHSTANDS 5000 F FOR 142 SEC compared to only 42 sec for a steel plate of the same thickness, recent tests show. The reinforced plastic is made of pure silica fibers combined with a "special high temperature phenolic resin binder." Potential uses for the plastic include liners, heat shields and nose cones for rockets and missiles.

GRAPHITE PARTS WITH GOOD THERMAL SHOCK RESISTANCE can be obtained by applying a carbide coating, recent research indicates. Applied to machined parts, the coating is said to be integrally bonded to the graphite even in undercuts, holes, drilled areas and milled sections. Potential uses include liquid reactor cores, aircraft honeycomb parts, containers for continuous evaporation of metals, and die casting inserts.

LARGE METAL POWDER PARTS, 10 to 12 in. in dia and weighing 8 to 9 lb, are said "to have the highest degree of uniformity ever achieved for a part of this type." The parts are produced by "proportional pressing" on a newly designed hydraulic press in which the two lower compacting "punches" start their upward compression strokes at different levels but arrive simultaneously at full compression level. A larger press in the same series, still to be built, will produce 14-in. dia pieces, according to the producer.

A U.S.-PRODUCED POLYPROPYLENE RESIN, similar in physical, mechanical and electrical properties to Montecatini's recently announced resin (see p 110) but made by a different process, is now commercially available. Like Montecatini's resin, the new thermoplastic has high heat resistance, good strength and toughness, and good

chemical resistance. Appliance parts, valves, hot water pipes and bottles are a few of the uses anticipated for the new resin. (More details next month.)

TUBING WITH EXCELLENT CREEP RESISTANCE and creep strength at temperatures from 1200 to 1500 F can be obtained by using a new austenitic heat resistant alloy. The alloy, containing nickel, molybdenum, tungsten, columbium and tantalum, is easy to fabricate and has better strength than conventional stainless steel tubular alloys. (More details next month.)

A FLAME SPRAYED CERAMIC COATING on automobile cylinders and pistons significantly reduces the amount of carbon monoxide and unburned hydrocarbon in exhaust gas. The catalytic coating also greatly improves combustion efficiency (by as much as 30%), provides good thermal insulation, and permits higher surface combustion temperatures. Chemical composition of the coating has not been revealed.

HIGHER OPERATING TEMPERATURES FOR COPPER- and nickel-base alloys can be obtained by dispersion strengthening with small particles of aluminum oxide. The process is said to permit the use of these metals at temperatures much nearer their melting points; the effect is much like a gravel reinforcement in an asphalt road which prevents the asphalt from flowing during hot summer days. Dispersion-strengthened copper- and nickel-base alloys should find use in such applications as aircraft parts, bearings, tools and dies.

A NEW ELECTRICAL GRADE PLASTICS COMPOUND, said to have good electrical and insulating properties at high humidities and relatively high temperatures (160 F), has been added to a family of boilable thermoplastics (see MATERIALS & METHODS, Mar '56, p 145). A polymethylstyrene compound, it is said to have good dimensional stability, low water absorption, and good chemical and wear resistance. According to the producer, the resin can be either molded or extruded into intricate electrical and electronic parts. (More details next month.)

ALUMINUM INVESTMENT CASTINGS WITH GUARANTEED PROPERTIES are now commercially available. The producer says it can guarantee in all areas of the casting the following properties: tensile strength, 34,000 psi; yield strength, 25,000 psi; and elongation, 3%. The castings are produced by an improved investment casting technique, details of which have not been revealed by the company. The castings are said to be useful as structural, load carrying aircraft parts.

Turn to page 149 for more "What's New in Materials"

MATERIALS BRIEFS

Spuds vs Dogs

Aluminum-foil-wrapped baked potatoes, served with butter and a plastics fork, may someday outsell hot dogs at sports events. Success of the baked potato, as indicated by a record sell-out at its introduction, is attributed to the aluminum foil wrapper which keeps the potato piping hot.

Chameleonic Paint

A deep blue paint detects "hot spots" in equipment by turning white where the temperature rises above 580 F.

A Fair Idea

A translucent reinforced plastics roof, 380 ft in dia and designed like a bicycle wheel, will top the U. S. pavilion at the 1958 Worlds Fair in Brussels.

Small But Bright

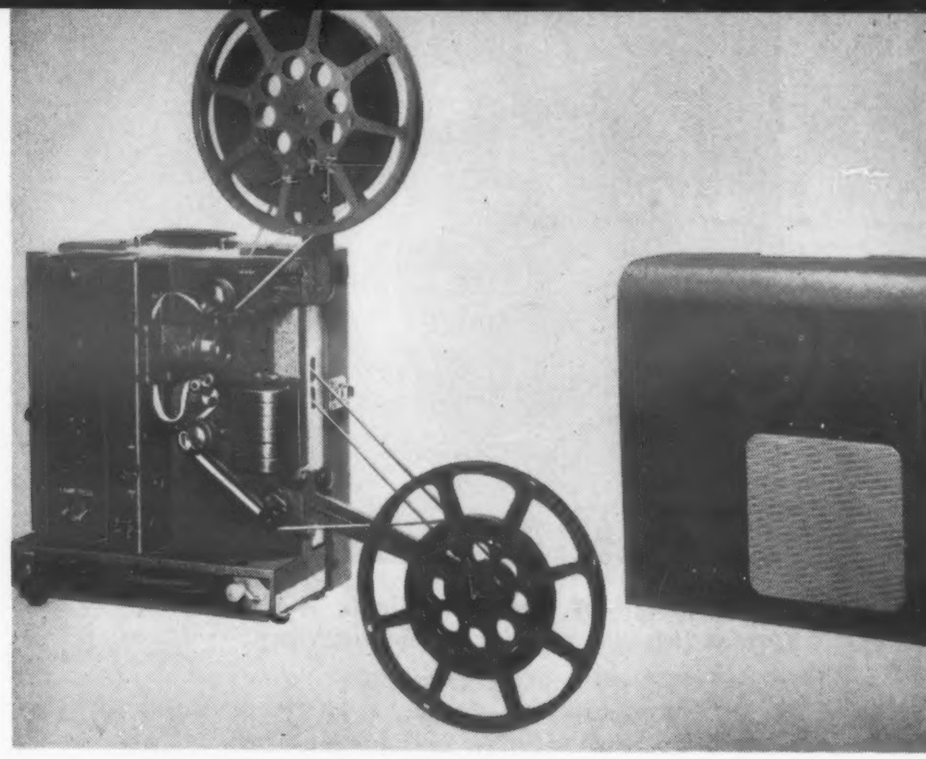
Shredded zirconium foil sheets are said to provide the most brilliant flash yet achieved by a flash bulb. The bulb is about one-fourth the size of ordinary flash bulbs. Most present-day flash bulbs use shredded aluminum as the flash source.

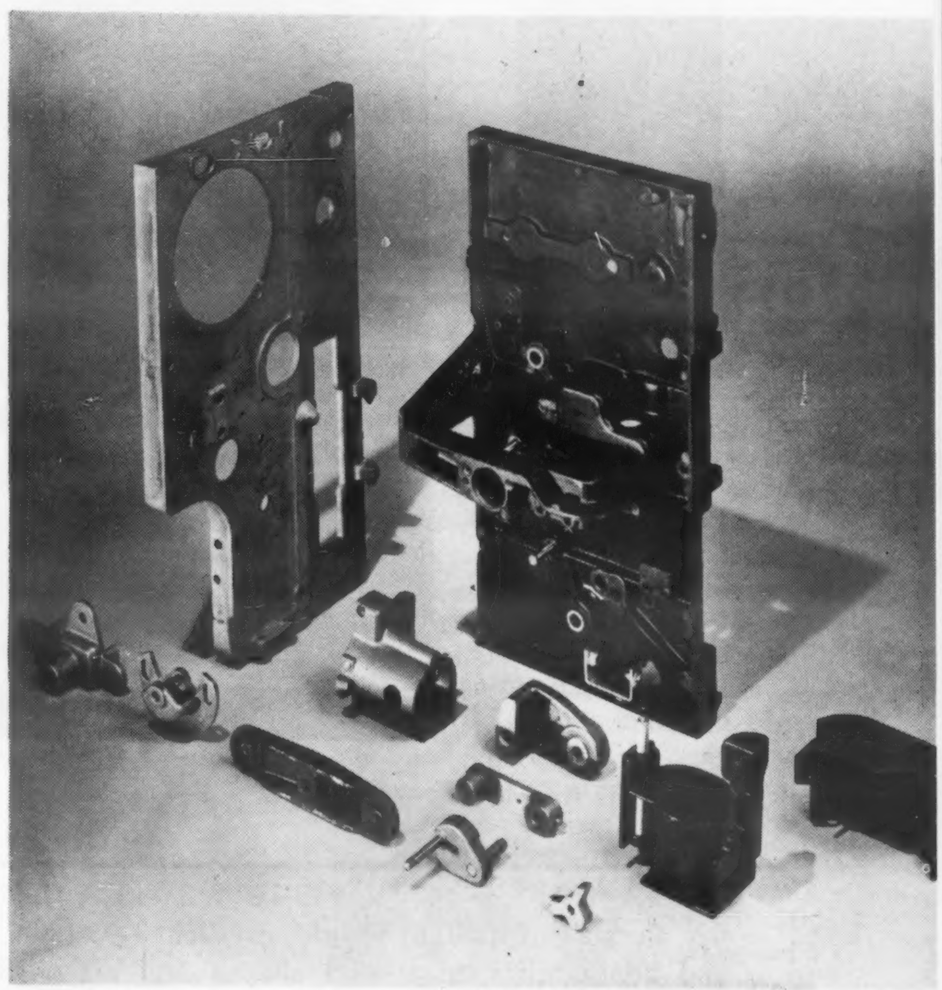
No Sinking Feeling

Copper sheathed plywood pontoons filled with foamed polystyrene are said to make catamaran-type cruisers virtually unsinkable. The foam provides permanent buoyancy, the plywood supplies the necessary structural strength, and the copper sheathing prevents fouling and marine growth. One boat weighs 49,000 lb and accommodates 15 passengers.

MATERIALS AT WORK

New and interesting applications of engineering materials

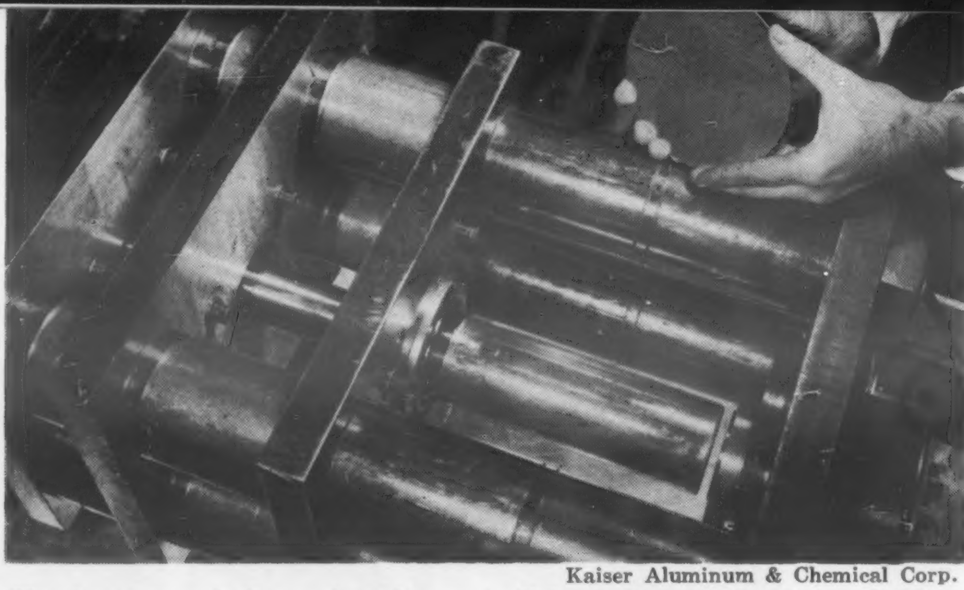




American Die Casting Institute

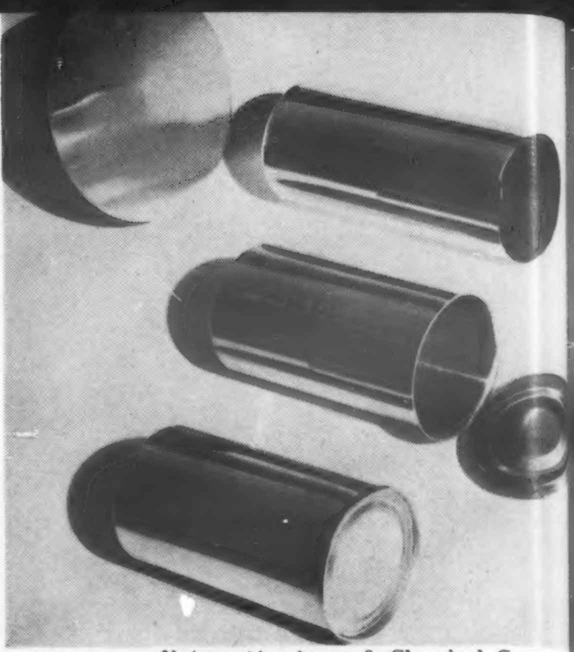
Magnesium die castings used in lightweight projector

The RCA 16mm sound projector shown at top has a 7-w amplifier, a speaker, a 1000-w prefocused projection lamp, and a reel capacity of 2000 ft—yet the entire assembly weighs only 33½ lb. The projector's light weight is attributable to extensive use of magnesium die castings. In addition to keeping weight to a minimum, the use of die castings is said to reduce the number of components necessary as well as eliminate several machining operations. The magnesium components (see bottom photo) are also said to be strong and dimensionally accurate.



Kaiser Aluminum & Chemical Corp.

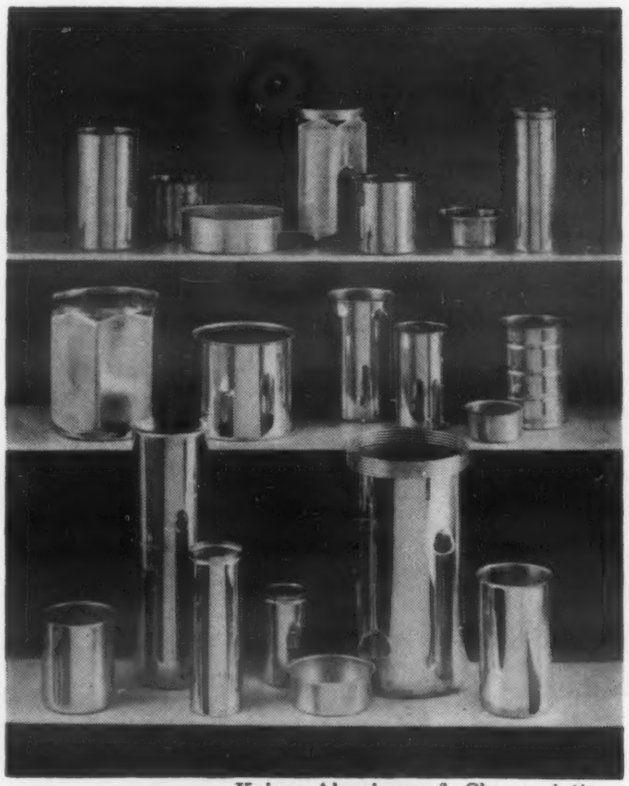
Final stage of deep drawing. *A disk similar to one being held is forced through a series of dies until can is formed.*



Kaiser Aluminum & Chemical Corp.

From disk to can. *Deep drawing produces single-piece can body and bottom which is trimmed, flanged and sealed.*

MATERIALS AT WORK



Variety of sizes *and shapes of cans possible with deep drawing.*

Kaiser Aluminum & Chemical Corp.

Aluminum cans

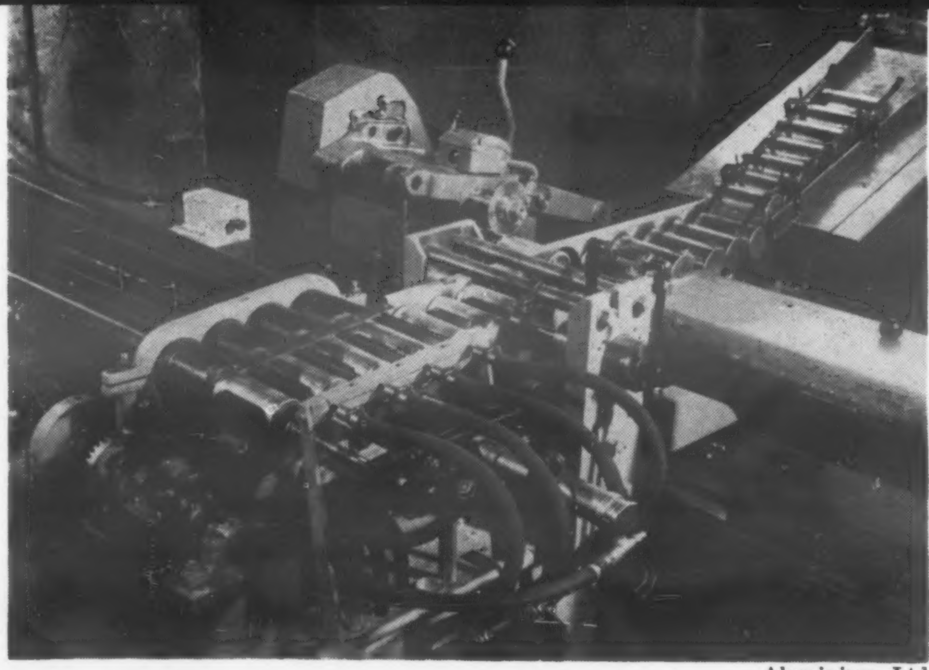
are made by . . .

Because of its light weight, excellent resistance to corrosion, and adaptability to special shapes and sizes, aluminum has long been considered an ideal material for cans. However, problems of cost, availability and fabrication had to be solved before aluminum cans could become practical. Intensive research along these lines has been conducted for more than five years, and within the last few months three major producers have come up with three separate fabricating techniques for the commercial production of aluminum cans for a variety of uses.

The importance of the aluminum cans has been debated vigorously ever since they were developed. Some observers feel that for certain uses the cans are not in a position to compete with conventional "tin cans." Others feel that aluminum's unique properties will overcome any cost disadvantages. In any event, aluminum cans are already being produced by the millions. Here is a report on the three techniques being used to produce the cans.

1. Deep drawing

A new deep drawing technique developed by Kaiser Aluminum & Chemical Corp. is said to produce a rigid, seamless aluminum can body and bottom in one piece with wall tolerances of ± 0.005 in. In conventional drawing operations, it is usually not possible to perform a draw greater than 50% of the diameter in one stroke; as a result, several forming operations would be required to bring the can body to its desired shape and size. With Kaiser's new method, however, the can body is formed in a single operation. In fact, it is now said to



Aluminium Ltd.

***Body finishing unit** forms base and flanges of impact extruded can.*

Aluminium Ltd.

***A variety of liquids** are being shipped in impact extruded cans.*

be possible to produce seamless can bodies with a depth of up to three times their diameter in a single stroke.

Briefly, the Kaiser method of producing aluminum cans involves four basic steps: 1) a disk cut from 3003 aluminum sheet alloy is drawn in a single stroke through a series of dies to form the can body; 2) the can body is trimmed and flanged; 3) a top is stamped on conventional stamping equipment; and 4) the can is filled and sealed with conventional double seaming equipment. Lacquering and decorating may be intermediate steps.

At present, Kaiser is producing aluminum cans in diameters up to 7 in. with wall thicknesses ranging between 0.005 and 0.250 in. However, equipment can be modified to produce other sizes.

2. Impact extrusion

A similar type of rigid, seamless aluminum can is being produced by Aluminiumwerke Goettingen, a subsidiary of Aluminium Ltd. However Aluminium is using the impact extrusion process. From slug to finished can, Aluminium's process is completely automatic and performed in one continuous operation as follows: 1) after the can body is formed it is fed down a hopper to a body finishing unit where the base is formed and the body trimmed and flanged; 2) the can is conveyed to a degreasing and washing unit; 3) after washing, the can is hot air dried and sprayed with lacquer; and 4) when the lacquer dries the can is automatically cooled, printed, filled and sealed.

Present equipment operated by Aluminium can handle cans from 2 to 3 in. in dia and from 2 to 6 in. in height. However, equipment can be modified for other sizes. According to the company, it should be entirely feasible in the future to further automate the line so that aluminum ingots will be melted and converted into a continuous strip from which the slugs would be punched and fed continuously into the press.

3. Conventional technique

The third major producer of aluminum cans, Reynolds Metals Co., is turning out production quantities using conventional can-making techniques. Several operations are necessary: 1) an automatic slitting machine cuts aluminum sheets into strips having widths corresponding to the circumference of the cans to be made; 2) at the same time, a multiple die press stamps can ends from aluminum sheet; 3) to insure smooth joints, the body blanks are notched at the corners and sent to a lock-seaming machine where edges are turned back; 4) the body blank is then wrapped around a mandrel, the edges are locked together and a hot melt cement is applied to form a tight joint; 5) convex plungers are forced into the ends of the cylinder, pressing the edges outward and forming flanges upon which to fit the can top and bottom; 6) the edges of the can ends are turned inward, a seam compound is applied and the bottom is attached to the can body with a double seaming machine; and 7) the can is filled and the top sealed.

At present, Reynolds is producing only one type of can: a 4-in. dia, 6-in. high motor oil can. A unique feature of the Reynolds aluminum can project is a system for reclaiming the metal. A special compressed air can-crushing device permits service station dealers to squeeze the used oil can into a flat coin-shaped slug for storage and for eventual salvage.

MATERIALS AT WORK

Eastman Chemical Products, Inc.

Butyrate oil container is transparent, durable

The handy oiler shown here is molded completely of tough, durable cellulose acetate butyrate. The oiler body, which holds up to 4 oz of lubricating oil, is molded of transparent amber material to enable the user to tell at a glance when it needs refilling. In addition to toughness, butyrate was selected for this application because of its resistance to oils.

Cast stainless components protect orange juice

Extensive use of cast stainless steel for pumps, valves, fittings, pipes, tanks and other vital units has solved the problem of moving 650,000 gal of cold orange juice from the S. S. Tropicana to the Whitestone, L. I., packing plant of Fruit Industries, Inc.

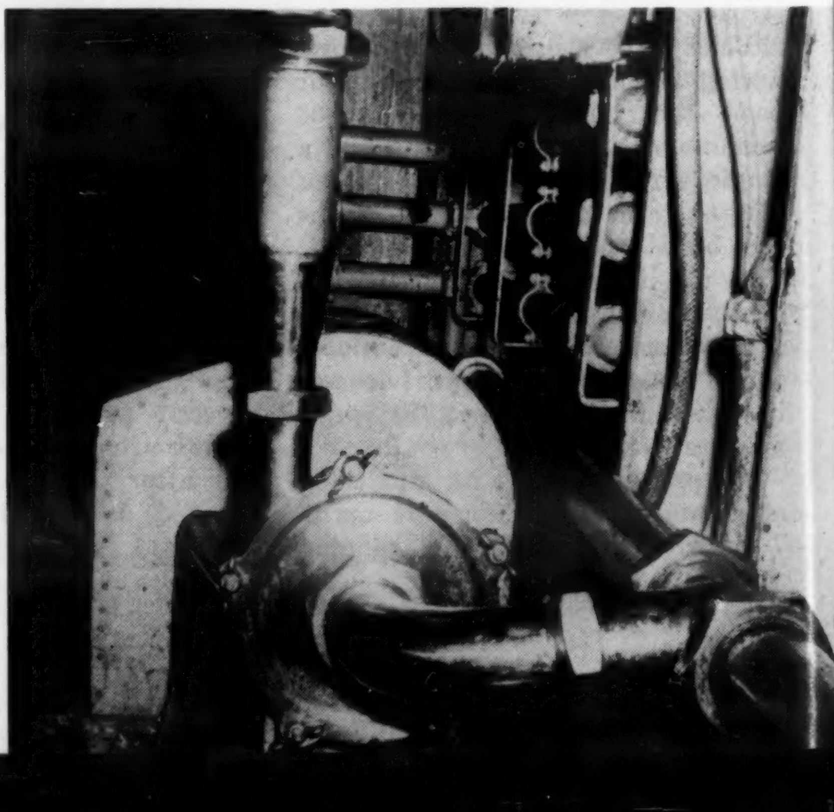
The orange juice, originally put on board in Florida, is stored at 28-30 F in insulated stainless steel tanks. Upon arrival in New York, the cold juice must be quickly pumped into the plant to prevent any rise in temperature. The juice is pumped out in stainless steel lines, fed through a chiller that lowers the temperature several degrees, and finally ends up in stainless steel mixing and holding tanks. From there the juice is piped to automatic carton-filling machines.

On board ship two stainless pumps handle the entire batch of orange juice. The pumps, each with 4 x 3-in. inlets and outlets, move 600 gpm.

(continued on p 174)

Pipe lines *transport juice from ship to receiving plant.*

Pumps *on board ship move juice out of tanks at 600 gpm.*



Synthetic rubber error

To the Editor:

In reading your very excellent "Guide to Synthetic Rubbers" presented in the Sept '57 issue of your magazine, we note what appears to be a transposition of lines. Table 14 on p 141 lists the maximum service temperature of silicone rubber. You list intermittent temperatures for general purpose rubber from 450 to 500 F, while continuous service is listed at 600 F.

ROBERT L. PARKIN
Assistant Advertising Manager
Dow Corning Corp.
Midland, Mich.

We hope our readers will correct this error. The lines are transposed.

Insulated pipe unions

To the Editor:

With all the talk about couple action between dissimilar metals, one would think electrically insulated unions of various types would be available for pipes of all sizes, and in all combinations of materials. But where can I get such a union with ¾-in. galvanized female at one end and copper (male or female) on the other? The purpose is to connect an ordinary hot water tank to copper plumbing.

C. W. MASON
School of Chemical Engineering
Cornell University
Ithaca, N. Y.

We don't know, but we'd be glad to hear from anyone who does.

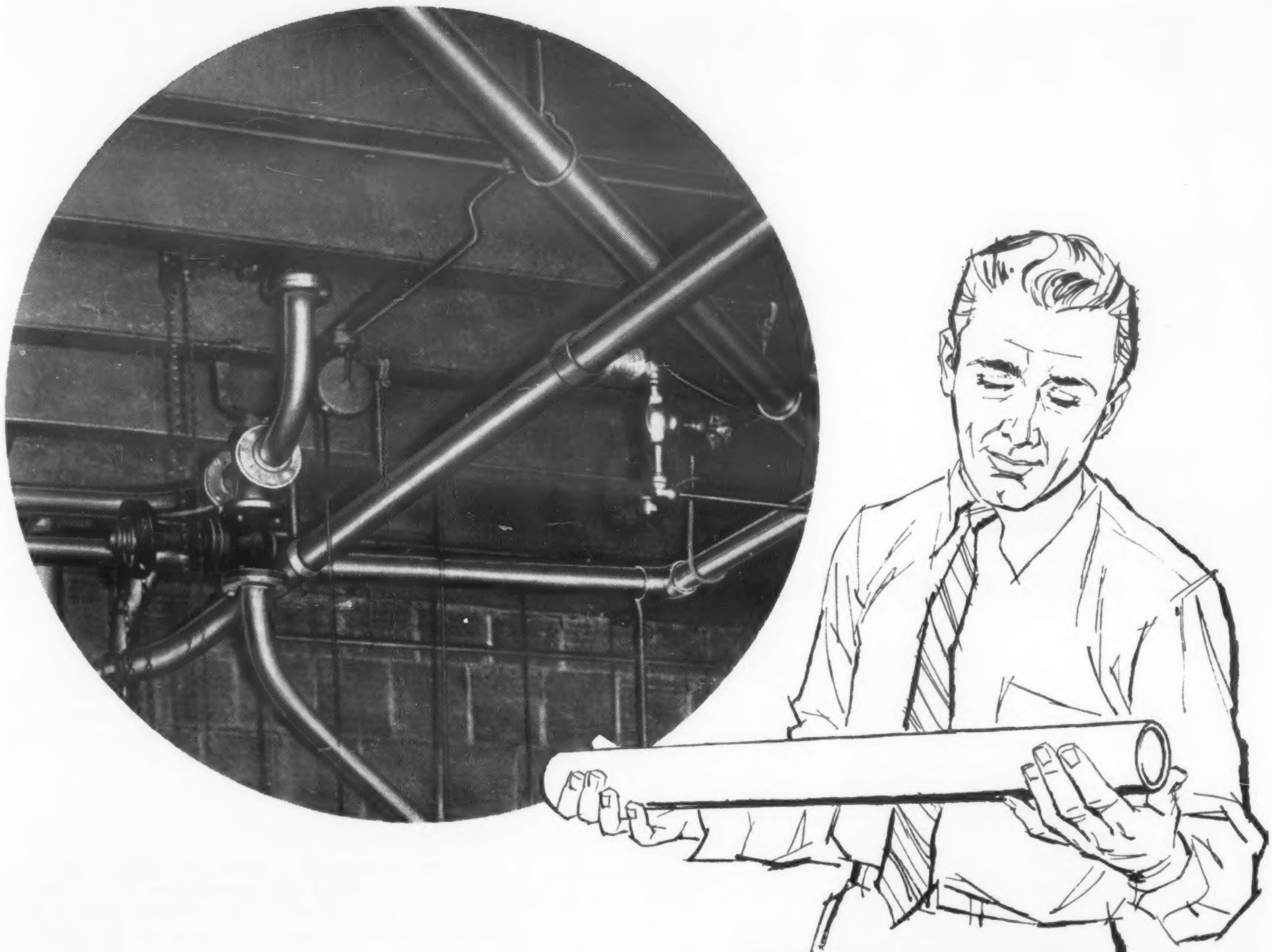
Titanium to-do

To the Editor:

Your October editorial on the titanium situation included a reference to Watertown Arsenal which might have given your readers an erroneous impression of the policy and attitude of the Arsenal with respect to encouraging nondefense applications of titanium.

Mr. Everhart's titanium manuscript, I must admit, did get poorly treated when it was sent here last summer, but the fault wasn't due to a lack of interest on the part of qualified reviewers. Because it was poorly directed, the manuscript failed to get into proper hands. It is not expected that this situation will recur.

I would like to emphasize that so far as I know the policy of Watertown Arsenal and other Government agencies with respect to encouraging nondefense applications of titanium is, if anything, firmer than it was a few years ago. The Dept. of Defense



"B&W fully annealed welded stainless steel pipe offers top corrosion resistance

I'm a plant engineer. My job is to keep the plant in operation under service conditions that are frequently rugged. And I've found that B&W Welded Stainless Steel Pipe gives me the maximum of time-in service, together with a minimum of maintenance."

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For further information, call Mr. Tubes, your nearest B&W representative—he can help you solve any tubing problem—or write for Bulletin TB410. The Babcock & Wilcox Company, Tubular Products Division, Beaver Falls, Pa.

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For more information, turn to Reader Service card, circle No. 510

has established a Titanium Metallurgical Laboratory at Battelle Memorial Institute to serve as a clearing house of information on titanium and its problems and uses. Increasing nondefense use of titanium should enable the titanium industry to reduce the price of titanium and thus permit its wider use in defense applications. Many possible applications of titanium to military components are inhibited solely by its present high cost. So, if for no other reason, this would be sufficient motivation for our encouragement of nondefense applications. There are many other good reasons, of course.

J. F. Sullivan
Associate Technical Director
Watertown Arsenal Laboratories
Watertown, Mass.

Fluoro-elastomers

To the Editor:

I am preparing a book on high temperature materials and would like permission to use information from an article—"The Fluoro-Elastomers"—published in the July '57 issue of Materials in Design Engineering.

Fred L. Coonan, Chairman
Dept. of Metallurgy & Chemistry
U. S. Naval Postgraduate School
Monterey, Calif.

Permission has been granted.

Wanted: filter that replaces itself

To the Editor:

I am interested in obtaining an air filter paper that is mounted on rolls on a frame in such a way that when the paper is dirty the difference in air pressure will cause clean paper to roll into place.

I read about this in some engineering paper when I was in the East last summer.

Paul C. Hansen
Denver, Colo.

Small fusible cylinders

To the Editor:

In connection with research and development work for the British Standards Institution, I am anxious to reproduce the shape of small cylindrical objects, less than 3 x 3 in., by casting around a metal pattern. The material should be a cold setting cement or a material fusible at less than 150 C. It is essential to use a material which will permit good reproduction of surface detail as well as extreme accuracy in the retention of dimensional tolerances.

W. D. Jones
Consulting Metallurgist
London, England

Can any of our readers help on these?

ONE POINT OF VIEW

Brains are back in style but science must be more than a fad

Have you noticed how crowded the science band wagon has become in the last few months? With so many in public life jumping aboard, there is hardly any room left for scientists. There was never any such overcrowding in the pre-Sputnik age. Then the wagon was sparsely occupied by scientists and eggheads, who now and then tried hard to make themselves heard. But they seldom succeeded. The public didn't care to hear. Now almost everyone at least is willing to listen to the urgent tunes being played.

Bandwagons are perishable

Although all of this recently generated enthusiasm for science is commendable, we must not expect it to work miracles. Much of it is superficial and of the crash program variety. It is easily forgotten when the apparent urgency is gone.

Indifference of the general public to science and other intellectual activity is a deep-seated trend in our American culture, and it cannot be reversed overnight. Recently when it was widely publicized that the Army was wastefully using a young mathematical genius for KP, most of us remarked: "That's just like the Army." But as Bill Mauldin pointed out, it is not only the Army who has been putting brains out with the garbage cans. All of us have been doing it for a long time.

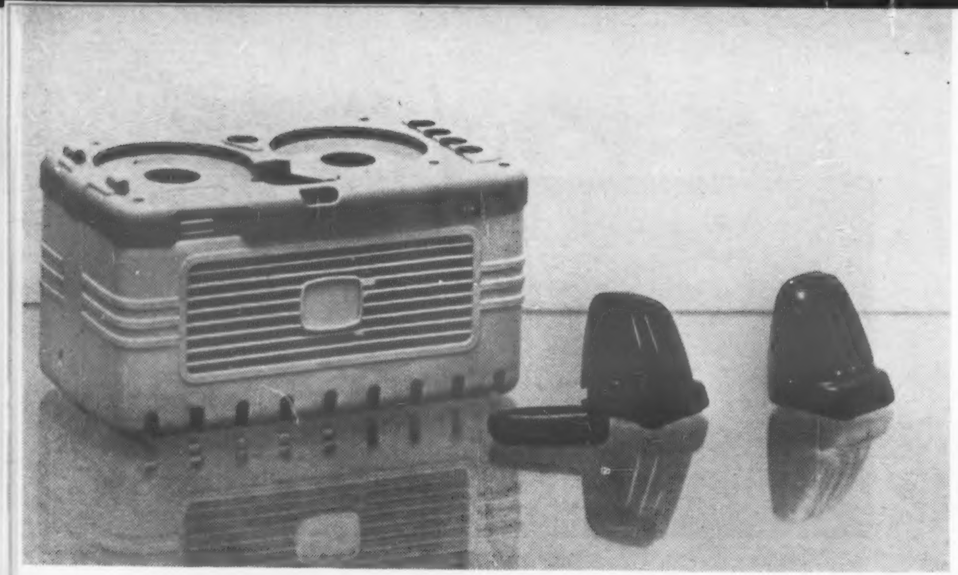
For years the mass public, including the well educated, has accepted the products of science —the autos, wonder drugs, tranquillizers and hydrogen bombs—without caring much about, or even being aware of, the principles and methods of science. The tacit assumption is that science, and the technology stemming from it, can thrive endlessly even when there is no interest in pure science for its own sake.

Disinterest is dangerous

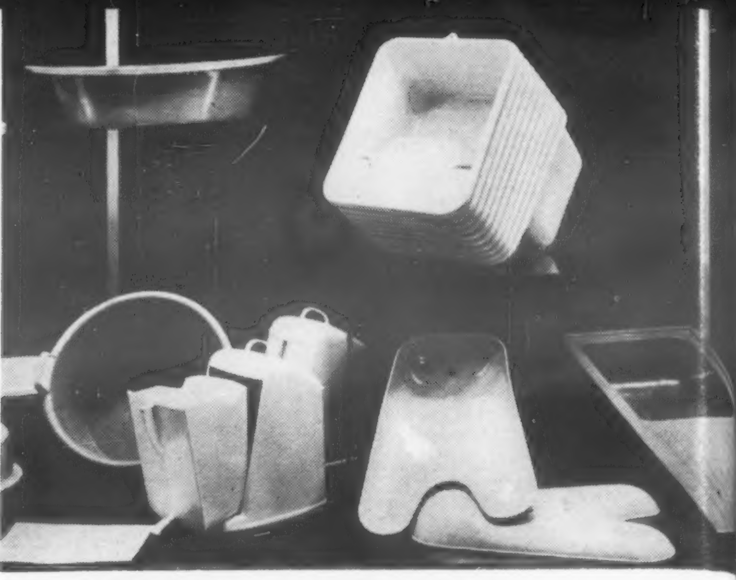
But this is a dangerous assumption. Science cannot continue to grow (and perhaps cannot survive) in a culture that ignores it. For what begins as disinterest and indifference often leads to ignorance, then to ridicule, and finally to suppression. As pointed out on this page last month, we have had numerous examples of this sequence of events in recent years.

A real understanding needed

To assure continued and rapid progress in science, we must somehow develop a genuine interest in the nature and methods of science. It must not be the kind of interest that leads to a blind faith in science and scientists such as the current wave of enthusiasm has a danger of doing. Rather, what we need is the kind of understanding and acceptance that comes from a real knowledge of the principles of scientific inquiry. Such an interest would develop a taste for ideas and an appreciation of the creative and adventuresome aspects of science; and it would recognize science as a way of thinking and as an important social force. Where we go from here depends largely on how soon and how well we acquire this understanding of science, and the burden of this challenge must ultimately fall on those who shape the American educational system.



***ELECTRICAL COMPONENTS**—Good dielectric properties, coupled with excellent thermal and mechanical properties, make uses such as tape recorder cabinets and microphone cases promising.*



***SANITARY-WARE**—Chemical stability and strength make polypropylene suitable for such applications as sinks, wash tubs, and garbage disposal and hygienic units.*

Polypropylene—

In this exclusive article the author discusses the properties, fabricating characteristics and potential applications of a new heat resistant thermoplastic material — the first comprehensive report to be published in this country.

by C. Crespi, *Montecatini Co.*

Structure of the New Plastic

Isotactic polypropylene is the first of a new class of alpha-olefin polymers discovered by Giulio Natta of the Milan Polytechnic Institute in 1954. A variety of polymers of this class can be produced depending on the monomer type, which can be propylene, butylene, styrene or mixtures thereof. Polypropylene is the first of this family to be produced commercially, following extensive industrial development under the sponsorship of Montecatini Co. Moplen is the trade mark for Montecatini's isotactic polypropylene.

Such polymers have a sterically regular structure within the macromolecule and thus are called "isotactic" polymers. Their main linear head-to-tail chains contain long sequences of tertiary carbon atoms presenting the same steric configuration. This type of stereoisomerism provides the polymers with new and unforeseen properties. They are tough, highly crystalline and have high melting points.

The isotactic polymers are obtained by means of heterogeneous catalysts, which are called "stereospecific" because they selectively direct polymerization toward the production of isotactic, high molecular weight materials.

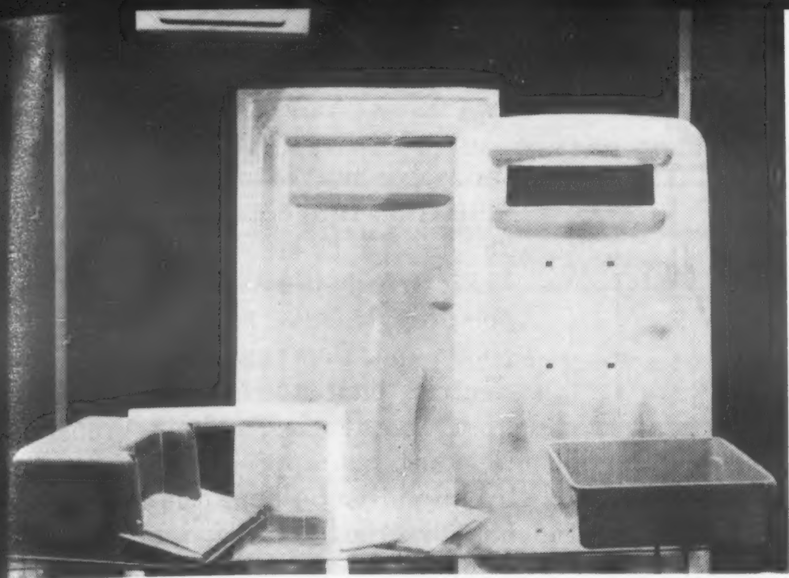
The chemical structure of polypropylene can be represented by the following simplified formula in which the tertiary carbon atoms with the same steric structure are marked with an asterisk:

■ Isotactic polypropylene is a tough, strong thermoplastic material with a high melting point. It is the first of a family of plastics produced by "constructing" the molecule so as to provide predetermined physical properties. Probably the plastic most similar to polypropylene is high density polyethylene; thus much of the data in this article compares these two materials. In general polypropylene, in comparison with high density polyethylene, is somewhat stronger and tougher, has higher heat resistance, and is about equal in chemical resistance and electrical properties.

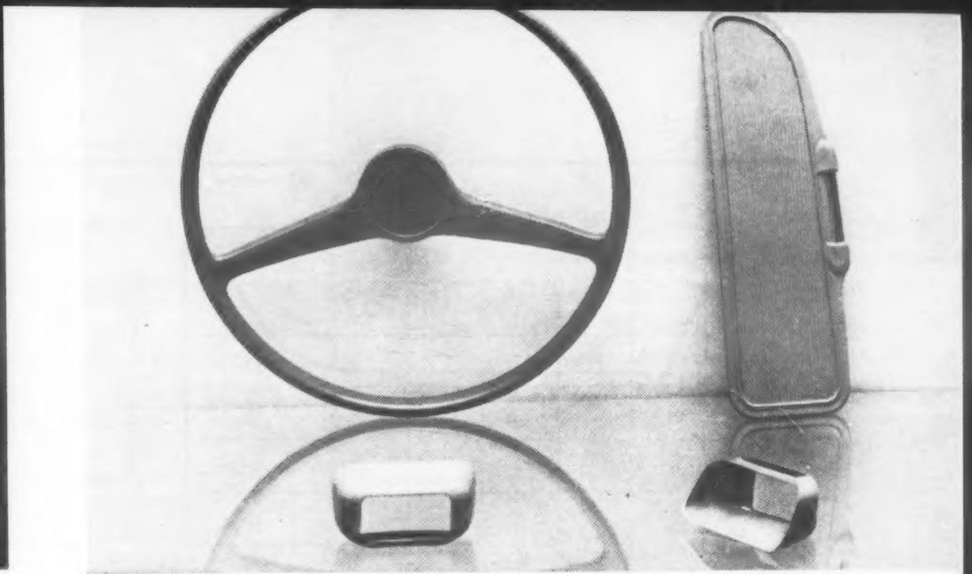
Properties

Polypropylene is a colorless, odorless thermoplastic material. Typical properties are shown in Table 1. The low specific gravity of polypropylene (0.90 to 0.91) can provide definite economic advantages over conventional thermoplastics.

Mechanical properties — The stress-strain curves (Fig 1) for polypropylene subjected to either tensile or compressive stresses are typical of a highly crystalline polymer having a low second order transition temperature (temperature at which amorphous polymer becomes brittle). Under an external tensile stress the material



***APPLIANCES**—Strength, rigidity and high surface finish of polypropylene make it promising for components of home appliances, such as refrigerators.*



***AUTOMOTIVE AND INDUSTRIAL PARTS**—Rigidity plus impact and abrasion resistance make polypropylene suitable for many automotive applications, such as steering wheels, sun visors and tail light frames.*

A Promising New Plastic

first undergoes an elastic deformation up to the yield point, after which the section of the specimen is suddenly reduced and the material stretches under constant stress. During this stretching the molecules become oriented and mechanical properties improve. Degree of improvement is a function of the degree of orientation.

Fig 1 also shows the remarkably high compressive strength of polypropylene. Compressive yield strength ranges from 8500 to 9900 psi, or about twice the tensile yield strength. When the material is stressed rather rapidly to 70 or 75% of the yield strength, it behaves elastically and no permanent deformation can be detected.

The effects of increasing temperature on stressed polypropylene are shown in Fig 2. The curves show the effects of temperature increases of 120° F per hour on samples stressed at 213 psi, and compare these effects on polypropylene with effects on high

Availability

Moplen, Montecatini's isotactic polypropylene, is available in limited experimental quantities from Chemore Corp., 21 West St., New York City.

TABLE 1—POLYPROPYLENE VS OTHER PLASTICS

Material ➡	ASTM	Isotactic Poly-propylene[a]	Polyethylene[b] Low Density	Polyethylene[b] High Density	Polystyrene[b] (high impact)	Polyvinyl Chloride (rigid)
PHYSICAL PROPERTIES						
Spec Grav (68 F)	D792	**0.90-0.91**	0.92-0.93	0.95-0.96	0.98-1.10	1.35-1.55
Bulk Factor	D1182	**2.25**	1.6-2.2[c]	1.6-2.2[c]	1.6-2.4	—
Ten Str, 1000 psi	D638	**4.3-5.7**	1.5-2.4	2.5-5.0	3.5-8.0	4.9-8.9
Elong (total), %	D638	**500-700**	400-700	10-300	10-30	—
Yld Str, 1000 psi	D638	**4.3-4.9**	1.1-1.7	2.5-5.0	—	5.0-6.5
Elong (at yield), %	D638	**10-20**	20-40	5-10	—	1-5
Stiffness in flexure, 1000 psi	D747	**114-170**	18-21	57-93	142-398	498-569
Young's Modulus, psi	Ultrasonic	**4.4-4.8 x 10^5**	—	—	—	—
Impact Str (Izod, unnotched), cm-kg/sq cm	D256	**>80**	—	—	—	—
Hardness (Rockwell)	D785	**R85-95**	—	R30-50	M15-65	R100-110
THERMAL PROPERTIES						
Melt Index, gm/10 min	D1238	**6-20[d]**	0.2-200	0.3-8.0	—	—
Melting Point, F	[e]	**329-338**	225-235	255-265	175-185[c]	165-175[f]
Softening Point (Vicat), F	DIN 57302[g]					
5-Kg Load	—	**>185**	—	180-190	165-185	195-205
1-Kg Load	—	**>284**	185-195	250-255	—	—
Brittleness Temp, F	D746	**<14**	−105	−105	—	—
Spec Heat, Btu/lb/°F		**0.46**	0.55	0.55	0.30-0.35	0.20-0.28
Coef of Ther Cond, Btu/hr/sq ft/°F/in.		**0.95**	2.9	2.32	0.29-0.87	1.16-1.45
Coef of Ther Exp, per °F	D696	**62 x 10^{-6}**	83 x 10^{-6}	56-58 x 10^{-6}	22-56 x 10^{-6}	28-78 x 10^{-6}
ELECTRICAL PROPERTIES						
Dielec Str (⅛in.), v/mil	D149	**769-820**	480	480	300-600	425-475
Dielec Const (10^6 cps)	D150	**2.0-2.1**	2.3	2.3	2.5-3.5	3
Dissip Factor (10^6 cps)	D150	**0.0002-0.0003**	<0.005	<0.005	0.001-0.010	0.01-0.02
Vol Res, ohm-cm	D257	**>10^{16}**	>10^{15}	>10^{15}	10^{13}-10^{17}	10^{12}-10^{16}

[a]Moplen.
[b]Source: *Technical Data on Plastics*, Manufacturing Chemists' Assn., Inc. (1957).
[c]ASTM D392.
[d]10-kg load used instead of 2.16 kg.
[e]Crystallographic microscopic.
[f]Second order transition point.
[g]German standard test method.

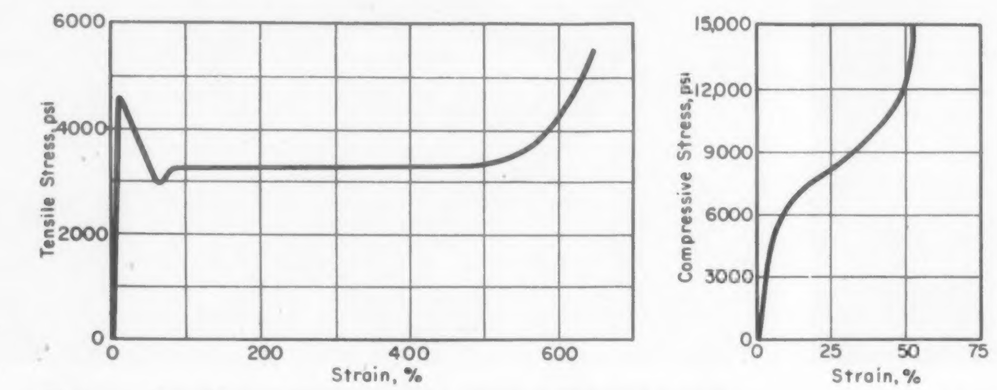


***Fig 1**—Tensile and compressive stress-strain curves.*

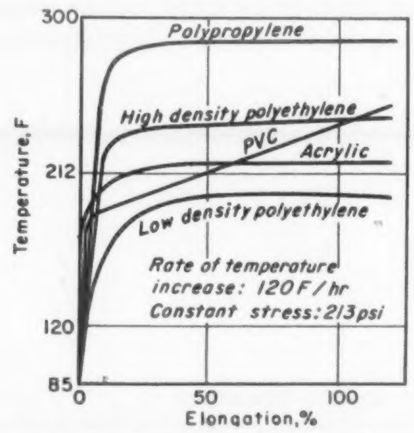


***Fig 2**—Effect of increasing temperature on elongation of various plastics under a constant stress.*

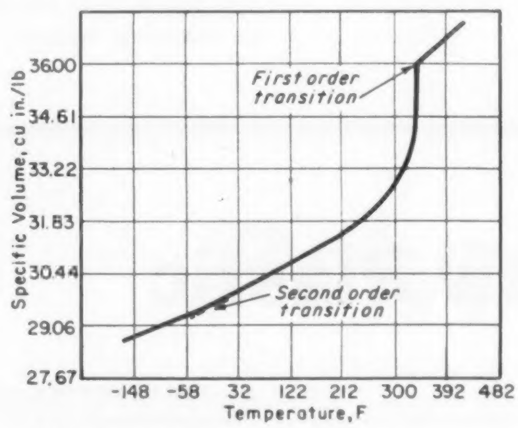


***Fig 3**—Specific volume vs temperature.*

and low density polyethylene, as well as polymethyl methacrylate and polyvinyl chloride.

As shown in Table 1 polypropylene has a relatively high degree of surface hardness (Rockwell R85 to R95) which, coupled with its high elasticity, provides unusually good abrasion resistance. Also, the material has a low coefficient of friction, making it particularly suitable for rotating parts such as gears or bearings.

Thermal properties—Polypropylene's exceptionally good resistance to heat is probably its most outstanding property. It has a melting point of over 300 F and a Vicat softening point (5-kg load) greater than 185 F. The material behaves as a crystalline solid even at temperatures above 212 F, permitting parts to be sterilized in boiling water.

The thermal nature of the material can be shown more specifically by the effects of temperature on specific volume. The curve of Fig 3 shows two characteristic points: 1) the first order transition temperature, corresponding to the melting temperature of the crystalline portions of the material (about 340 F), and 2) the second order transition temperature, corresponding to the embrittlement temperature of the amorphous portions of the material (about –30 F).

In the absence of external stresses, formed polypropylene parts do not change their shape on exposure to temperatures up to 300 F (see photo sequence, p 113).

Isotactic polypropylene melts over a very narrow temperature range. The material is still in a solid state at 310 F, yet it is completely molten at about 345 F. Just above the melting point the material has the consistency of an uncured rubber, i.e., it is viscous and elastic. Viscosity decreases with molecular weight and with increasing temperature. Cooling a molten sample rapidly crystallizes the polymer, the maximum crystallization rate occurring at about 250 to 265 F.

Electrical properties—Isotactic polypropylene is essentially nonpolar and thus has excellent dielectric characteristics even at high frequencies. These properties are not appreciably affected by humidity because the material has practically no water absorption. Since the electrical properties of polypropylene are in many cases similar to those of polyethylene, the benefits of using polypropylene for electrical applications are primarily derived from the combination of its dielectric properties and its superior mechanical and thermal characteristics.

Chemical properties—Because of its molecular structure isotactic polypropylene is quite resistant to many chemical reactants, both acid and alkaline, even at high temperatures. Effects of several chemicals on weight, tensile strength and elongation are shown in Table 2. Polypropylene's resistance to saline solutions is also good, even at temperatures over 212 F.

Table 3 shows effects of some solvents on polypropylene. At room temperature polypropylene is insoluble in all organic solvents and is not embrittled upon contact with such solvents or polar substances. At temperatures above 175 F the material is soluble in aromatic substances such as toluene and xylene, and in chlorinated hydrocarbons such as trichloroethylene or tetrachloroethylene. These solvents cause some swelling at room temperature. Resistance to solvents increases with increasing crystallinity of the material.

As shown in Table 3, effects of mineral and vegetable oils are extremely small. No change in physical properties can be detected after immersion for 30 days.

Oxidation resistance — Polypropylene becomes sensitive to oxygen at elevated temperatures. The addition of small amounts (0.5 to 1.0%) of suitable antioxidants serves to stabilize the

Heat resistance of unstressed moldings—a comparison

TABLE 2—EFFECTS OF ACIDS AND ALKALIS ON POLYPROPYLENE[a]
(Properties After Exposure)

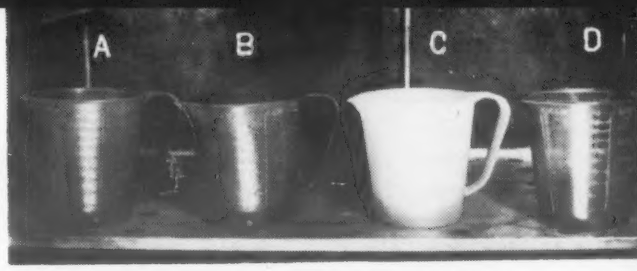
Reagent ↓	Test Time, Days	Temperature, F	Weight Increase, %	Tensile Strength, psi[b]	Total Elongation, %	Other Effects
None (control)......	....	68....	—	4270	440	—
Sulfuric Acid (80%)	30....	68....	Negligible	4170	480	Sl coloring
	7....	158....	Negligible	4690	400	Sl coloring
	7....	194....	Negligible	4690	410	Sl coloring
Sulfuric Acid (98%)	30....	68....	Negligible	4125	230	Sl coloring
	7....	158....	Negligible	4690	270	Acid turns dk brown.
	7....	194....	Negligible	4765	30	As above; crazes
Nitric acid (50%)	30....	68....	Negligible	3980	335	Crazes; acid turns yellow
	7....	158....	0.1	5120	20	
	7....	194....	3.2	1705	—	Embrittles
Nitric acid (94%)	30....	68...	0.2	4095	60	—
	7....	158....	6	1422	—	Embrittles
Hydrochloric Acid (conc)	30....	68....	0.2	3980	350	—
	7....	158....	0.3	4125	330	—
	7....	194....	0.5	4550	280	—
	7....	230....	0.3	4690	270	—
Sodium Hydroxide (40%)	30....	68....	Negligible	4690	380	—
	7....	158....	Negligible	4690	360	—
	7....	194....	Negligible	4690	350	—
	7....	230....	Negligible	4780	300	—

[a]Moplen. [b]ASTM D638-52T.

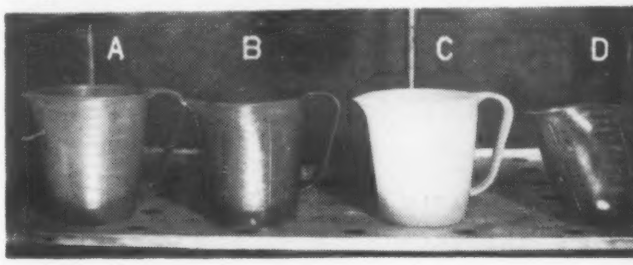
TABLE 3—EFFECTS OF SOLVENTS AND OILS ON POLYPROPYLENE[a]
(Properties After Exposure)[b]

Solvent ↓	Weight Increase, %	Tensile Strength, psi[c]	Total Elongation, %[c]
None (control)..........	....	4270	440
Auto Gasoline..........	13.2	3695	700
Benzene..........	12.5	3770	690
Carbon Tetrachloride..........	41.3	3840	720
Acetone..........	2.0	3695	600
Olive Oil..........	0.1	4080	383
Mineral Oil..........	0.3	4125	350
Transformer Oil..........	0.2	4125	—

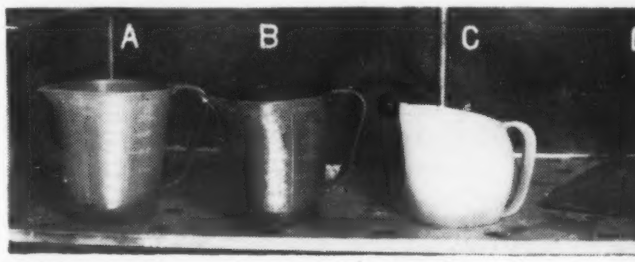
[a]Moplen. [b]Exposure: 30 days at 68 F. [c]ASTM D638-52T.



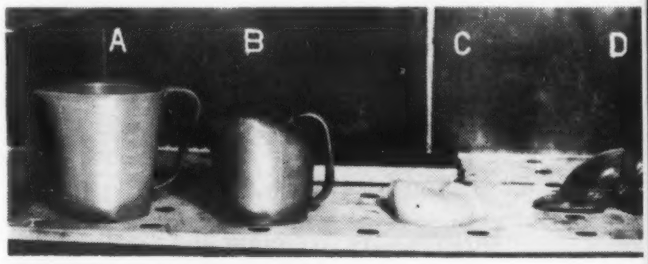
90 F—*All cups dimensionally stable. (A—polypropylene, B—high density polyethylene, C—low density polyethylene, D—polystyrene)*



212 F—*Polystyrene shows substantial deformation.*



255 F—*Low density polyethylene collapses; high density polyethylene deforms.*



300 F—*Polypropylene alone remains unaffected.*

material even when it is subjected to processing treatments lasting several hours at temperatures as high as 390 F.

Most polypropylene supplied by Montecatini is marketed in stabilized form. Practical tests show that no appreciable depolymerization occurs even after several extrusions of the stabilized material at 390 F.

Photo - oxidative degradation, similar to that encountered with polyethylene, can be avoided by adding to the polymer substances which shield it from ultraviolet light. For example, parts containing small amounts of carbon black do not undergo any alteration either in appearance or in physical properties after two years' exposure outdoors. In accelerated aging tests (ASTM D 620-49T), no changes take place in physical properties of carbon black-filled material after 3000 hr of exposure; unfilled samples become embrittled after only 200 hr.

Molding and fabricating

Equipment and techniques for molding and fabricating polypropylene are generally similar to those used for handling other thermoplastics. The material can be extruded; injection, compression and vacuum molded; dip coated; and machined with conventional tools. Solutions of the material can also be used for spread coating and impregnating. Although polypropylene is somewhat compatible with other materials such as natural and synthetic rubbers, polybutenes, waxes and mineral oils, in most applications it should be used alone. No plas-

ticizer is required for processing.

Following is a brief discussion of the forming techniques applicable.

Extrusion—Extrusion tests indicate that increase of extrusion rate with pressure is greater than with low density polyethylene; thus polypropylene has better flow characteristics under normal extrusion pressures. Recommended extrusion temperatures range from 340 to 355 F for the barrel and 375 to 430 F for the nozzle, depending on the shape to be extruded.

Blowing—Blowing is particularly suitable for manufacturing containers and bottles, both squeezable and rigid. The process consists essentially of extruding a cylindrical pipe which, while still hot, is put in a mold where the final shape is obtained by blowing. Temperatures recommended for the extrusion part of this operation are 345 to 365 F for the barrel and 410 to 430 F for the nozzle. The gas used for blowing does not require heating.

Injection molding—Because of polypropylene's good flow characteristics it is particularly well suited to injection molding. Although the material has a high melting temperature, which requires high mold temperatures, the cycles can be very short since the high dimensional stability of the material permits parts to be extracted from the mold at relatively high temperatures (about 212 F). Linear shrinkage is about 3%. By using carefully plated molds, polypropylene parts can be produced with smoother and more brilliant surfaces than possible with many of the other thermoplastics.

Other techniques—Compression molding, though usually used for thermosetting plastics, can be used to advantage for polypropylene when parts such as flat sheets, plates or blocks are required. Centrifugal molding techniques can be used to produce such shapes as large diameter pipe.

Dip coatings can be applied to metal surfaces by heating the surface to temperatures of about 480 to 575 F prior to dipping into the polypropylene powder. After the coating is applied, it should be heated in an oven at 480 F to provide a uniform smooth finish.

Polypropylene sheet and film can be drawn or vacuum formed. Films 0.008 to 0.01 in. can be drawn to form boxes and other containers. Thicker material, such as sheet, should usually be vacuum formed.

TABLE 4—PERMEABILITY OF FILM—POLYPROPYLENE vs POLYETHYLENE (77 F)

Reagent ↓	Polypropylene[a]	Polyethylene (low density)
PERMEABILITY TO GASES[b]		
Carbon Dioxide	**0.60**	1.44
Oxygen	**0.18**	0.35
Hydrogen	**0.70**	0.89
Nitrogen	**0.04**	0.12
Methane	**0.08**	0.41
PERMEABILITY TO VAPORS[c]		
Water	**0.20**	0.35
Ethanol	**0.05**	0.28
Ethyl Acetate	**3.13**	11
Acetone	**0.30**	2.8
n-Heptane	**131**	93
Toluene	**94**	130
Carbon Tetrachloride	**221**	160
PERMEABILITY TO LIQUIDS[d]		
Water[e]	**8.20**	0.31
Ethanol	**0.05**	0.24
Ethyl Acetate	**2.9**	11.8
Acetone	**0.29**	2.35
n-Heptane	**295**	120
Toluene	**165**	180
Carbon Tetrachloride	**370**	230

[a]Moplen.
[b]10^7cu cm/sq cm/cm/sec/atm
[c]Film 0.10 mm thick in contact with vapors only; units are gm/sq m x 24 hr.
[d]Film 0.10 mm thick in contact with liquid; units are gm/sq m x 24 hr.
[e]Dessicant method: ASTM E96-53T.

TABLE 5—PHYSICAL PROPERTIES OF FILM—POLYPROPYLENE VS OTHER PLASTICS

Plastic ➜	Polypropylene[a]	Polyethylene (low density)	Cellophane
Tensile Strength, psi[b]			
Lengthwise	**5000-5700**	2700-2800	4300-18,500
Transverse	**3900-4700**	2500-2700	—
Elongation, %[b]			
Lengthwise	**600-700**	270-290	14-15
Transverse	**650-750**	220-240	—
Tear Resistance, lb/in.[c]			
Lengthwise	**950-1000**	480-500	112-500
Transverse	**840-900**	400-450	—
Linear Dimensional Change After Heat Exposure, %[d]			
Lengthwise	**0**	−6	—
Transverse	**0**	+2	0.7-4.2

[a]Moplen.
[b]ASTM D882-54T.
[c]ASTM D1004-49T.
[d]ASTM D1204-54; 212 F, 30 hr.

Applications

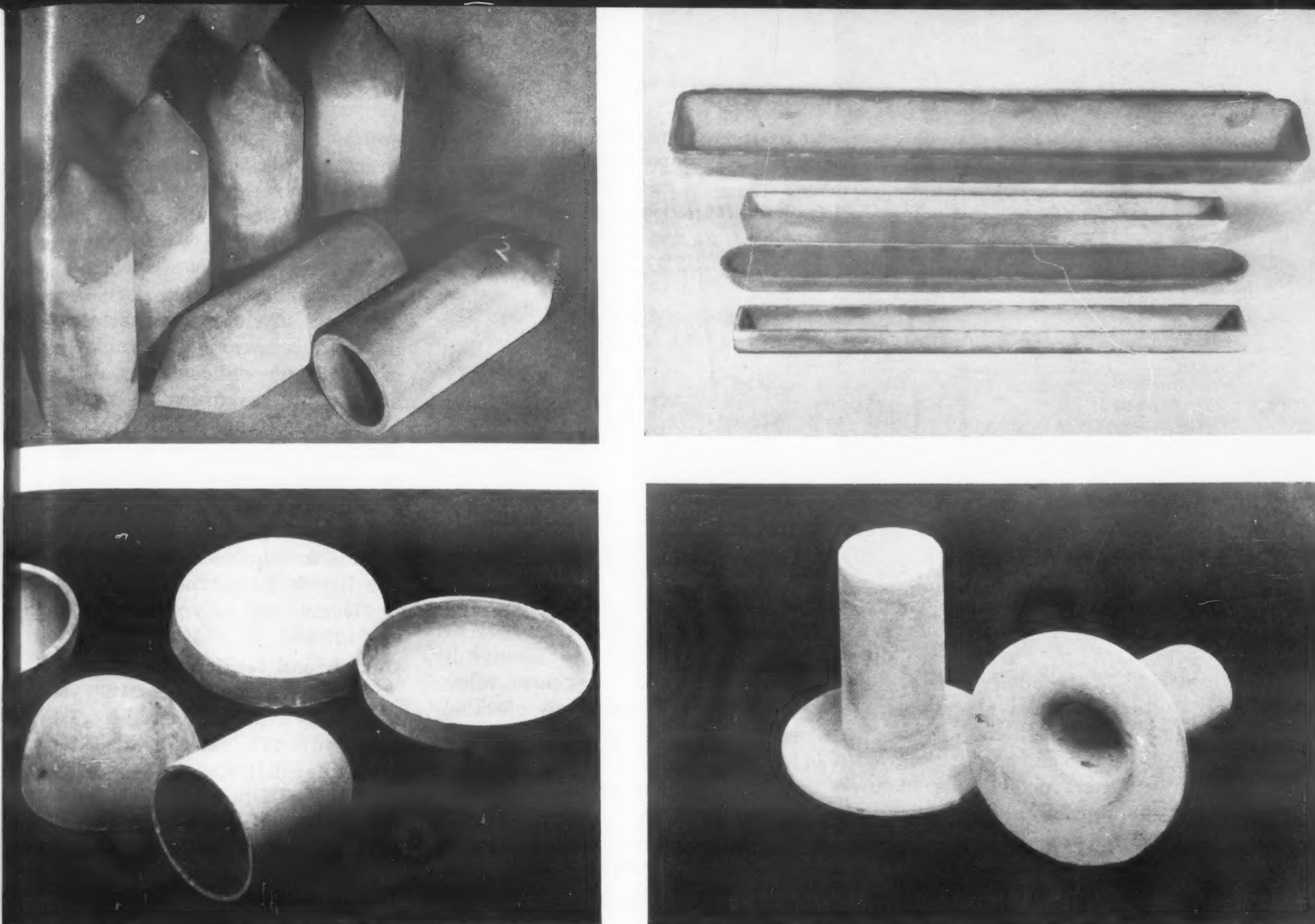
Because of the combination of properties unique to polypropylene, the range of applications for the material is extremely wide. The material is now being used in Europe and in all likelihood will be used in the United States in the form of moldings, sheet, film and fiber.

The yield strength of polypropylene, which is considerably higher than that of known polyethylenes, indicates interesting possibilities for the material as structural parts, particularly in the piping field where the material's chemical resistance provides additional benefits. Long-time tests are curmaximum permissible loads in relation to environmental conditions of use.

The combination of high surface hardness, elasticity and low friction coefficient make polypropylene particularly promising for rotating parts of machines such as typewriters, calculating machines and radios.

Packaging applications for polypropylene film appear most promising. Table 4 shows the relatively low permeability of the film to gases, vapors and liquids. Table 5 compares properties of the film with those of other commercial packaging films.

Other potential applications are indicated by the photographs shown on pp 110 and 111.



Crucibles and boats *of silicon nitride are used for synthetic mica processing (top left), zone refining of semiconductors (top right), drawing of transistor metal crystals (bottom left), and handling molten nonferrous metals in laboratory processing (bottom right).*

Silicon Nitride Refractory offers . . .

- *High temperature stability*
- *Resistance to molten nonferrous metals*
- *Good thermal shock resistance*

Here is the property and design information needed to specify this relatively new refractory.

by T. F. Frangos, *Haynes Stellite Co., Div. of Union Carbide Corp.*

■ Among refractory materials, silicon nitride is outstanding for its resistance to molten nonferrous metals and its excellent chemical stability at elevated temperatures. It will also withstand attack by molten steel and cast iron for shorter periods of time. Silicon nitride has a modulus of rupture about midway between those of aluminum oxide and silicon nitride-bonded silicon carbide. It has good thermal shock resistance and high temperature stability. This combination of properties has permitted silicon nitride to be used successfully in applications such as rocket nozzles and thermocouple tubes for molten aluminum.

SILICON NITRIDE COMPARED WITH OTHER MATERIALS

Material ➡	Silicon Nitride	Aluminum Oxide	Silicon Carbide	Graphite	Cast Iron	Stainless Steel (type 316)
Melting Point, F	3452[a]	3722	4712[a]	6582[a]	2066-2500	2500-2550
Density, lb/cu in.						
Theoretical	0.124	0.140	0.115	0.081	0.252-0.277	0.287
Actual	0.111	—	—	—	—	—
Hardness						
Eberbach[c]	2400-4300	1900	2400-3200	—	—	—
Rockwell A[d]	99	60[e]	70[e]	—	60.5	48.5-52.5
Mod of Rupture (rm temp), psi	10,000	37,700	4000-6500	1800	—	—
Ther Cond (400-2400 F), Btu/hr/sq ft/°F/in.	10.83	19-30	21-81	7.3-2.2	310	113-149[b]
Coef of Ther Exp (68-1832 F), per °F	1.37	4.3	2.42	1.2	5.8-7	6.2

[a]Sublimes.
[b]212-932 F.
[c]Obtained on individual grains.
[d]Obtained on slip cast parts.
[e]Subject to wide variation depending on binder used.

Physical properties

General properties of silicon nitride are compared with those of other materials in the accompanying table. Silicon nitride does not have a true melting point but, like other refractories, decomposes by sublimation at about 3450 F. It has been used successfully in neutral or reducing atmospheres at temperatures up to 3400 F.

Unit volume weight of silicon nitride is about 30% greater than that of graphite; approximately equal to that of silicon carbide; and less than half that of cast iron and steels.

Modulus of rupture is about 10,000 psi—higher than those of silicon carbide and graphite, but not as high as that of aluminum oxide. Relatively little information is available on the modulus of rupture of silicon nitride at elevated temperatures. Field observations made at temperatures up to 2000 F indicate that the material loses little if any strength at elevated temperatures.

Silicon nitride has no ductility as measured by the standard metal tensile test. Its impact resistance is similar to that of alumina.

Since silicon nitride has a strength comparable to other ceramic materials and a much lower coefficient of thermal expansion, it should have thermal shock characteristics better than those of most ceramics. Thin-walled thermocouple protection tubes have been removed from a 3400 F furnace and cooled to room temperature in still air with no thermal shock failures. Though it is not necessary to preheat tubes before using them at elevated temperatures, preheating will lengthen their service life.

Thermal conductivity is extremely low, e.g., one-half that of aluminum oxide and one-fifth that of silicon carbide or steel.

Resistance to molten metals

Silicon nitride is resistant to attack by molten nonferrous metals to the extent that it does not even appear to be wetted by them. The following results were obtained by filling slip-cast crucibles with metal and heating them to temperatures above the metals' melting points:

Metal	Metal Temp, F	Time, hr	Effect
Al	1472	950	No attack
Al	1832	100	No attack
Pb	752	144	No attack
Sn	572	144	No attack
Zn	1022	500	No attack
Mg	1382	20	Sl attack
Cu	2120	7	Hvy attack

Subsequent testing in molten aluminum at 1800 F has been carried out for over 3000 hr with no attack occurring.

Chemical resistance

Silicon nitride is resistant to attack by most acids. Compacts have been suspended in various concentrations of hydrochloric, nitric, sulfuric and phosphoric acid solutions for 500 hr or longer with no indication of attack. Testing is complicated by the porosity of silicon nitride which makes weight-gain measurements impractical because of pickup of corrodent in the pores of the test pieces. However, careful visual and petrographic examinations show that compacts were not attacked during the test period.

Silicon nitride is not attacked at room temperature by chlorine or hydrogen sulfide gases. It is attacked by solutions of sodium hydroxide stronger than 25%. Specimens immersed in boiling 50% caustic show indications of attack after 115 hr. Molten caustic soda at 842 F attacks silicon nitride in 5 hr. An accompanying box lists some corrodents that do and some that do not attack silicon nitride.

Design and fabrication

Silicon nitride parts are commercially available as slip castings, although experiments indicate the material can also be pressed and sintered, or extruded. Since production of silicon nitride parts involves forming silicon

Chemical Stability of Silicon Nitride

Not attacked by:

HCl (20%, boiling)
HNO_3 (65%, boiling)
HNO_3 (fuming, boiling)
H_2SO_4 (10%, 160 F, air-free)
H_2SO_4 (77%)
H_2SO_4 (85%)
HPO_3
$H_4P_2O_7$
$NaOH$ (25%)
Cl_2 (wet gas, 85 F)
H_2S (gas, 1830 F)
H_2SO_4 (conc + $CuSO_4$ + $KHSO_4$, boiling)
$NaNO_3$ + $NaNO_2$ (salt bath, 660 F)
$NaCl$ + KCl (salt bath, 1455 F)

Attacked by[a]:

$NaOH$ (50%; boiling), 115 hr
$NaOH$ (molten, 840 F), 5 hr
HF (48%, 160 F), 3 hr
3% HF + 10% HNO_3 (160 F), 116 hr
$NaCl$ + KCl (salt bath, 1650 F), 144 hr
$NaB(SiO_3)_2$ + V_2O_5 (2010 F), 4 hr
NaF + ZrF_4 (1470 F), 100 hr

[a] Tests were discontinued at the times indicated (the times at which corrosion was first observed).

metal powder into the desired shape and sintering in a nitrogen atmosphere, the outside dimensions of parts are limited by the size of the nitriding furnace and by the problems of handling relatively weak green castings.

Slip casting is the principal means of producing silicon nitride shapes and has the distinct advantage of making possible intricate and irregular shapes of a wide range of sizes. The process is as follows: A water slip of extremely fine silicon powder is poured into a plaster mold having an internal contour exactly that of the desired finished shape. As the plaster absorbs moisture from the slip, particles of silicon are deposited, building up a layer on the plaster surface. Since the number of particles deposited increases with time, thickness of the green part depends on the length of time the slip remains in the plaster mold. After the desired wall thickness is built up, the green part is nitrided in a furnace. Though solid pieces can be produced by slip casting, the process is most applicable to hollow shapes. Sections as thin as 1/16 in. have been slip cast successfully.

The green shape holds finished tolerances extremely well during the nitriding cycle. Though there is a slight contraction away from the plaster mold during casting, there is a compensating expansion of the material during nitriding. Thus the finished shape will generally be within ± 0.005 in. per in. of the dimensions of the pattern used to make the plaster mold. Careful support of the green shape is not required when nitriding slip cast, long tubular parts. Thin-walled silicon nitride thermocouple protection tubes are consistently cast to a center line tolerance of $\pm 1/32$ in. per ft.

Pressed shapes are made by pressing silicon metal powder of 150 mesh or finer into the finished form, then nitriding in a furnace. The voids between individual silicon particles provide paths for nitrogen to make intimate contact with each silicon particle. Thus all the silicon is transformed to silicon nitride, with no foreign bonding agent to present a source of potential weakness.

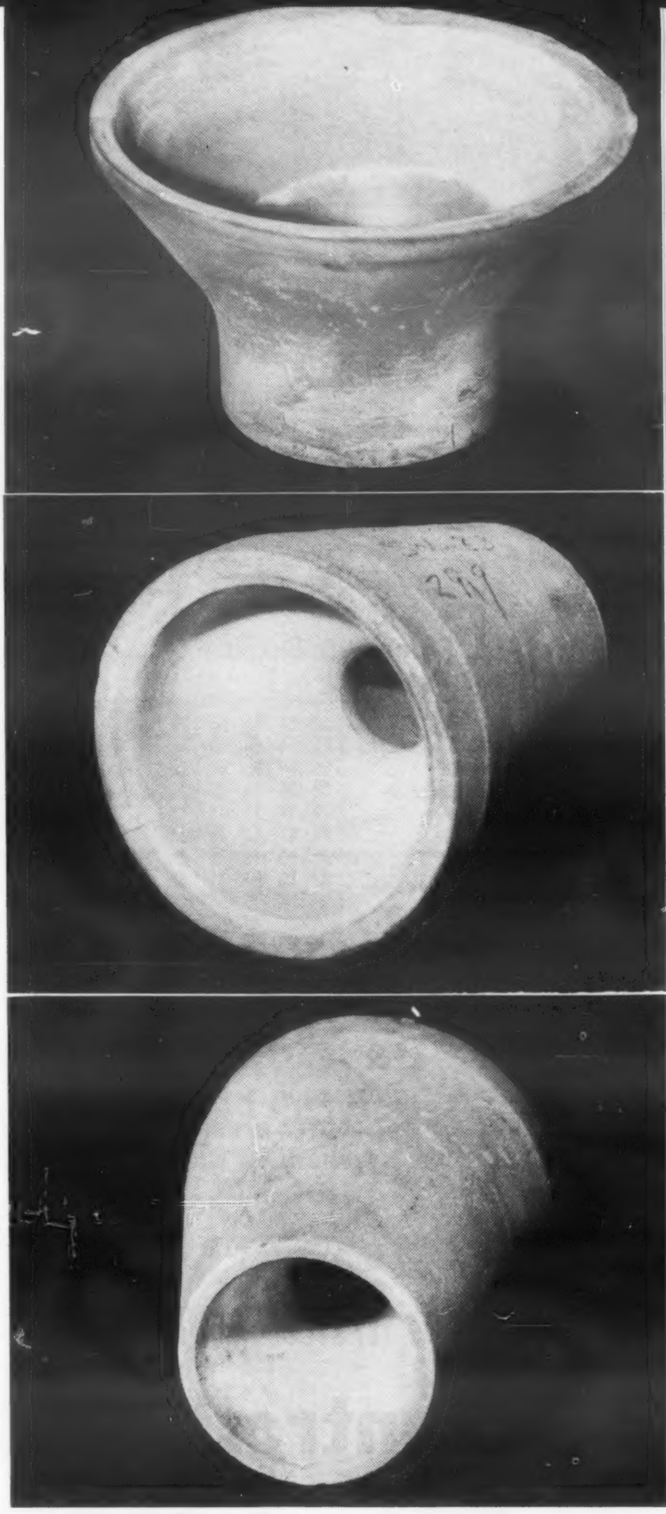
Pressing techniques are ideal for simple, straight-line solid bodies. Long thin-walled tubes must be fabricated by other techniques. Parts with 3-in. wall thickness have been successfully pressed and nitrided on a laboratory scale.

Extrusion techniques seem to be capable of producing thick-walled tubes or solid bars and rounds. Parts have been produced by extruding fine silicon in the form of a thick paste and then nitrided.

In producing silicon nitride shapes by any of the above techniques, there is theoretically no limitation on the size of section that can be nitrided as long as the individual particles of silicon are no larger than 150 mesh. Actually, slip cast thin sections nitride better and more completely than thick sections. The forming technique has no significant effect on the mechanical characteristics of the end product. Nitrided parts have an approximate density of 80% of theoretical regardless of fabrication technique.

When designing for silicon nitride parts, allowance should be made for draft to permit easy removal of a green casting from its mold. Sharp inside corners and abrupt changes of section are undesirable because of the materials inherent brittleness.

Silicon nitride can be machined with carbide tools, but care must be observed to avoid chipping and cracking. Grinding is somewhat difficult.



Rocket nozzle inserts *of various configurations are a promising application for silicon nitride.*

Applications

The transistor industry appears to be a likely user of silicon nitride in the form of crucibles and boats for crystal growing and zone refining, respectively. Silicon nitride is now under test to determine its suitability for use in processing both germanium and silicon metal, since neither wets the silicon nitride.

Silicon nitride inserts have been tested in both liquid and solid propellant rocket motors. Performance so far has been consistently fair in comparison with other refractories. Though silicon nitride is not the best performer in static tests of liquid and solid propellant motors, its low density may be significant in a missile where weight is critical.

Thermocouple protection tubes and pouring spouts for use in molten aluminum are other possibilities now under study. Despite its low thermal conductivity, silicon nitride's resistance to attack by aluminum may make it practical for thermocouple protection tubes, permitting automatic control of aluminum melts.

Reference

Collins, J. F., and Gerby, R. W., "Silicon Nitride—A Refractory Material," AIME Annual Meeting, Feb '55.

SUPERFICIAL ROCKWELL HARDNESS OF LIQUID CARBURIZED STEELS

Steel C1120

Case Depth, in. ↓ / Scale… / Temper Temp, F[a]	R_{15N} 350	R_{15N} 600	R_{15N} 750	R_{15N} 850	R_{30N} 350	R_{30N} 600	R_{30N} 750	R_{30N} 850	R_{45N} 350	R_{45N} 600	R_{45N} 750	R_{45N} 850
WATER QUENCHED												
0.000	77	76	76	68	52	52	51	46	38	38	36	29
0.001	80	78	77	74	59	57	55	48	43	39	38	31
0.002	83	82	80	77	64	61	60	53	44	41	39	34
0.003	85	84	83	81	67	64	63	55	52	44	43	37
0.004	87	86	85	82	71	67	65	58	[illegible]	48	46	39
0.005	88	87	86	84	73	68	66	60	[illegible]	[illegible]	[illegible]	41
0.006	90	88	87	85	76	70	67	61	61	53	51	44
0.007	91	89	88	85	78	71	68	63	63	55	53	45
0.008	92	89	88	86	80	72	69	65	65	57	55	47
0.009	92	89	88	85	81	73	70	66	68	60	56	48
0.010	93	89	88	86	82	74	71	67	75	63	57	49
OIL QUENCHED												
0.000	64	64	61	58	30	30	30	28	<20	<20	<20	<20
0.001	64	64	63	60	30	30	30	29	<20	<20	<20	<20
0.002	66	66	66	65	36	36	34	33	<20	<20	<20	<20
0.003	72	72	70	70	41	39	37	36	<20	<20	<20	<20
0.004	77	77	75	73	48	44	41	40	21	21	21	20
0.005	82	81	80	76	55	50	47	43	28	27	27	25
0.006	85	83	81	78	60	55	52	46	33	30	30	28
0.007	87	85	84	81	65	59	57	50	35	35	35	30
0.008	90	88	86	83	69	63	62	54	45	40	39	31
0.009	91	89	87	85	72	66	65	57	52	45	42	40
0.010	91	89	87	86	76	69	67	62	57	50	44	43

Steel C1010

Case Depth, in. ↓ / Scale… / Temper Temp, F[a]	R_{15N} 350	R_{15N} 600	R_{15N} 750	R_{15N} 850	R_{30N} 350	R_{30N} 600	R_{30N} 750	R_{30N} 850	R_{15N} 350	R_{15N} 600	R_{15N} 750	R_{15N} 850
WATER QUENCHED												
0.000	49	49	46	46	<20	<20	<20	<20	MINUS READINGS			
0.001	54	49	47	47	<20	<20	<20	<20	↓	↓	↓	↓
0.002	61	53	51	51	<20	<20	<20	<20	↓	↓	↓	↓
0.003	69	60	59	59	32	27	23	<20	↓	↓	↓	↓
0.004	79	71	69	66	42	30	29	25	<20	↓	↓	↓
0.005	83	77	76	71	48	38	36	33	<20	<20	<20	<20
0.006	87	82	80	75	53	43	38	35	<20	<20	<20	<20
0.007	90	84	82	78	60	48	42	37	25	<20	<20	<20
0.008	91	86	84	81	68	55	48	42	43	<26	<20	<20
0.009	91	88	86	83	73	61	56	50	51	<33	<29	<25
0.010	92	89	87	84	78	66	62	58	60	< 3	<99	<30
OIL QUENCHED												
0.000	46	46	43	40	<20	<20	<20	<20	MINUS READINGS			
0.001	47	46	44	43	<20	<20	<20	<20	↓	↓	↓	↓
0.002	50	48	47	46	<20	<20	<20	<20	↓	↓	↓	↓
0.003	58	55	53	50	<20	<20	<20	<20	↓	↓	↓	↓
0.004	66	62	59	56	26	21	<20	<20	↓	↓	↓	↓
0.005	72	68	66	63	27	22	21	<20	↓	↓	↓	↓
0.006	78	73	71	68	28	26	22	20	<20	<20	<20	↓
0.007	81	78	76	72	45	40	36	32	<20	<20	<20	↓
0.008	84	82	80	76	49	44	39	33	<20	<20	<20	<20
0.009	[illegible]	85	83	79	55	49	44	39	27	<20	<20	<20
0.010	[illegible]	[illegible]	[illegible]	[illegible]	64	54	50	47	36	<20	<20	<20

Steel B1112

Case Depth, in. ↓ / Scale… / Temper Temp, F[a]	R_{15N} 350	R_{15N} 600	R_{15N} 750	R_{15N} 850	R_{30N} 350	R_{30N} 600	R_{30N} 750	R_{30N} 850	R_{45N} 350	R_{45N} 600	R_{45N} 750	R_{45N} 850
WATER QUENCHED												
0.000	62	62	60	57	32	32	28	28	<20	<20	<20	<20
0.001	66	64	63	62	37	32	30	30	<20	<20	<20	<20
0.002	73	68	67	66	47	39	34	33	<20	<20	<20	<20
0.003	76	74	73	70	50	45	39	38	<20	<20	<20	<20
0.004	83	79	77	75	56	52	43	41	31	26	23	<20
0.005	86	83	80	78	61	57	47	45	40	31	30	<20
0.006	88	85	82	81	65	62	52	50	46	34	33	<20
0.007	91	87	84	83	69	65	57	54	53	37	36	<20
0.008	92	88	85	84	73	68	61	58	58	43	40	<20
0.009	92	89	86	84	76	70	64	61	61	48	46	25
0.010	93	89	87	85	79	71	67	64	65	52	51	30
OIL QUENCHED												
0.000	57	57	55	54	26	26	26	25	<20	<20	<20	<20
0.001	59	59	58	55	26	26	26	26	<20	<20	<20	<20
0.002	61	60	59	58	27	27	27	27	<20	<20	<20	<20
0.003	64	63	62	61	31	29	29	29	<20	<20	<20	<20
0.004	68	67	65	64	34	32	32	32	<20	<20	<20	<20
0.005	72	71	69	68	37	36	35	35	<20	<20	<20	<20
0.006	76	75	73	71	42	38	37	37	<20	<20	<20	<20
0.007	78	77	76	75	46	40	39	38	<20	<20	<20	<20
0.008	82	81	79	77	51	48	46	45	<20	<20	<20	<20
0.009	84	83	82	80	55	53	51	49	32	30	30	[illegible]
0.010	86	85	84	83	65	60	56	54	38	38	34	34

[a]Quenched directly from carburizing bath at 1550 F, tempered 20 min at indicated temperature.

1. Develop a correlation between superficial hardness and depth of carburized case. This table gives such a correlation for three steels and eight heat treatments. Limit the selection of a hardness scale to those sensitive enough to yield significant variations; in this table, these limitations have been shown by shading the insignificant hardness values.

This article gives a step-by-step procedure for

Controlling Carburized Case Depth

by a Superficial Rockwell hardness test.

by R. L. Suffredini,

Winchester-Western Div., Olin Mathieson Chemical Corp.

About This Article

Quality control of carburized parts can be achieved by rapid nondestructive hardness testing. As applied to liquid carburized gun parts, this procedure has resulted in higher testing speed and lower cost compared with the fracture test and microscopic methods used previously. Parts failing to meet specifications can usually be reprocessed and salvaged.

In developing the procedures discussed, it is necessary to make a survey of the effects of the case depth and various hardening treatments on the resulting hardness values. Correlation is obtained by making a Superficial Rockwell determination, sectioning the sample and determining the case depth by microscopic examination.

References

Adam, William, Jr., and Rosseau, L. B., "Modern Heat Treating," *Metal Progress*, Mar '50, p 332; Apr '50, p 498; June '50, p 765.

Lysaght, V. E., *Indentation Hardness Testing*, Reinhold Publishing Corp., 1949.

Suffridini, Romeo, "Non-Destructive Control of Shallow Carburized Case Depths," *ASTM Bulletin*, July '57, p 74.

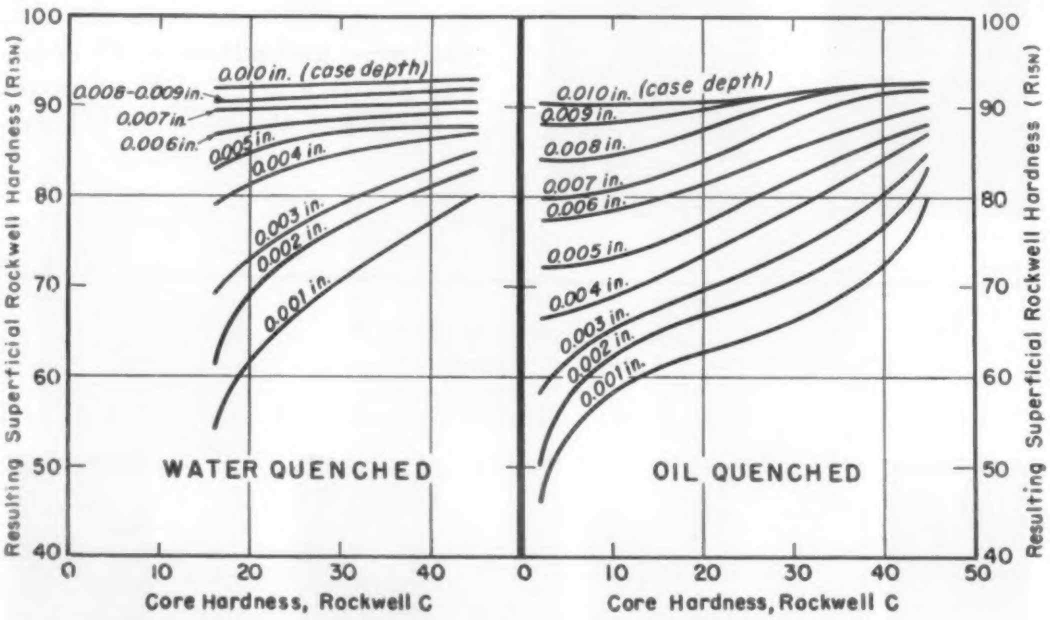
Sutton, R. S. and Heger, R. H., "Correlation of Published Data for Correction of Rockwell Diamond Penetrator Hardness Tests on Cylindrical Specimen," *ASTM Bulletin*, Oct '53, p 40.

2. Correct for different geometry with a table such as this one. The previous table is a correlation for flat parts, whereas hardness values determined on cylindrical specimens, for example, tend to be lower. Filing flat spots on production parts would damage them; instead develop an additional correlation between hardness values obtained from the two shapes and use it to correct the first table (1) for non-flat parts. In this case, simply add appropriate values obtained from the table at right to the Superficial Rockwell values in the first table.

CORRECTIONS FOR CYLINDRICAL SPECIMENS[a]

Dial Reading ↓	Cylinder Diameter, in.					
	1/8	1/4	3/8	1/2	3/4	1
20	6.0	3.0	2.0	1.5	1.5	1.5
25	5.5	3.0	2.0	1.5	1.5	1.0
30	5.5	3.0	2.0	1.5	1.0	1.0
35	5.0	2.5	2.0	1.5	1.0	1.0
40	4.5	2.5	1.5	1.5	1.0	1.0
45	4.0	2.0	1.5	1.0	1.0	1.0
50	3.5	2.0	1.5	1.0	1.0	0.5
55	3.5	2.0	1.5	1.0	0.5	0.5
60	3.0	1.5	1.0	1.0	0.5	0.5
65	2.5	1.5	1.0	0.5	0.5	0.5
70	2.0	1.0	1.0	0.5	0.5	0.5
75	1.5	1.0	0.5	0.5	0.5	0
80	1.0	0.5	0.5	0.5	0	0
85	0.5	0.5	0.5	0.5	0	0
90	0	0	0	0	0	0

[a]To be added to Rockwell 15N, 30N and 45N values.
Source: *Sutton and Heger.*



3. Allow for effect of core hardness. These curves show how Superficial Rockwell hardness varies with core hardness on material liquid carburized at 1550 F, water or oil quenched, and tempered at 350 F. As the curves indicate, the effect of core hardness decreases as case depth increases. This effect must be considered in setting production limits. The normal spread of hardenability of a material affects the resulting superficial hardness value, but results obtained from testing many heats of steel with different hardenability characteristics indicate that this variation in a single heat is not significant.

RECOMMENDED LIMITS OF SUPERFICIAL ROCKWELL SCALES

Superficial Rockwell Hardness Scale	AISI Steel and Treatment[a]	Case Depth Limit, in.
15 N	1120 O.Q.	0.007 max
	1120 W.Q.	0.004 min
	1112 O.Q.	0.007 min
	1112 W.Q.	0.007 min
	1010 O.Q.	0.010 min
	1010 W.Q.	0.007 min
30 N	1120 O.Q.	0.006 min
	1120 W.Q.	0.003 min
	1112 O.Q.	0.006 min
	1112 W.Q.	0.005 min
	1010 O.Q.	0.008 min
	1010 W.Q.	0.005 min
45 N	1120 O.Q.	0.007 min
	1120 W.Q.	0.006 min
	1112 O.Q.	0.010 min
	1112 W.Q.	0.006 min
	1010 O.Q.	—
	1010 W.Q.	0.008 min

[a]Direct quench from liquid carburizing bath at 1550 F.

4. Select hardness scales. On the basis of the initial correlation (1) and the preceding graph, select the Superficial Rockwell scales that will give best results for the case depths involved. The above table shows the limiting case depths for each of three Superficial Rockwell scales.

TYPICAL PRODUCTION STANDARDS

Shape	Spec	Case Depth, in.	Quenching Medium	Temper Temp, F	Data Hardness Range[a]	Production Standard Hardness Range[a]
Flat	B1112	0.004-0.006	Oil	350	68-76	65-75
Round[b]	C1010	0.003-0.005	Water	600	55-68	53-65[c]
Flat	Core R_C25	0.002-0.004	Water	350	72-83	70-85
Flat	Core R_C35	0.003-0.005	Oil	350	77-84	75-85

[a]R_{15N} scale. [b]1/4-in. round. [c]Adjusted by correction factor in Table 2.

5. Establish production standards. The standards shown at left are typical of those set by the methods described and have been used in production for four years.

How Radiation Affects Six Organic Coatings

by Lt. Lloyd A. Horrocks,
Wright Air Development Center, Air Research and Development Command

■ The effects of nuclear radiation on the properties of various engineering materials have been described extensively in recent years (for example, see "How Nuclear Radiation Affects Engineering Materials," MATERIALS & METHODS, Aug '54, pp 109-120). To date, however, little information has been published describing the effects of radiation on organic coatings. As shown in the accompanying photos, all organic coatings exhibit some change in properties when they are irradiated. This article, believed to be the first of its kind, describes just what these property changes are, and how the various coating systems rank in order of their resistance to radiation.

How damage is caused

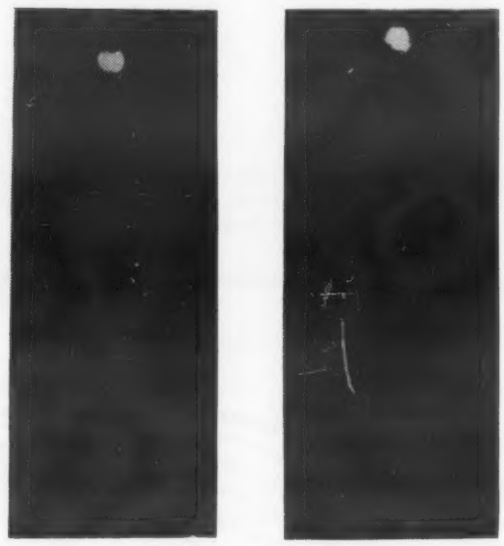
The extent of the change in properties of an organic coating depends on the nature and chemistry of the coating and the kind and dosage of radiation received. There are several kinds of radiation. In or around a nuclear re-

continued on p 122

Here are the coatings tested and how they rank in resistance to gamma radiation judging from the data compiled to date (approximate limits of radiation resistance in roentgens are given after each coating):

Radiation exposure: 1×10^9
Heat exposure: 50 hr at . . .

250 F | 500 F

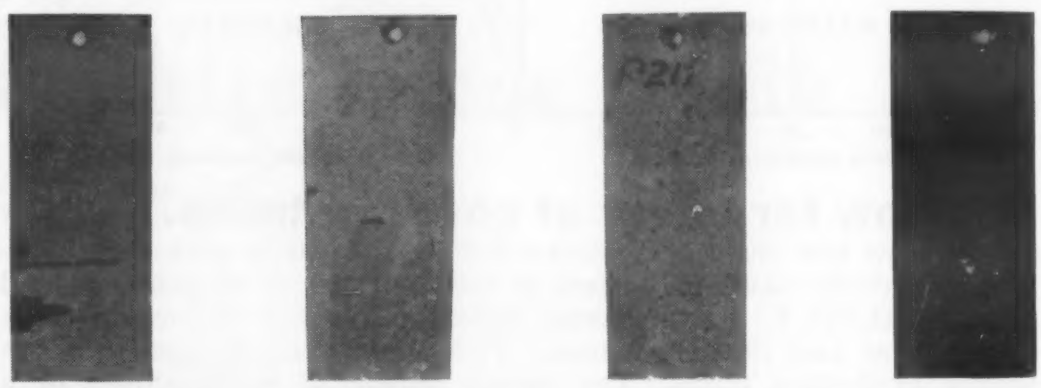


1. Phenolic coatings
(> 5×10^9 r)

In general, irradiated phenolic coatings baked 50 hr at 500 F retain their properties better than any of the other coatings evaluated. As shown, the surface appearance of test panels is unchanged after exposure. In addition to maintaining good abrasion resistance and adhesion, the coatings are little affected by exposure to 100% RH at 120 F for 28 days.

Heat exposure: 50 hr at 500 F
Radiation exposure (r):

0 | 1×10^8 | 1×10^9 | 5×10^9



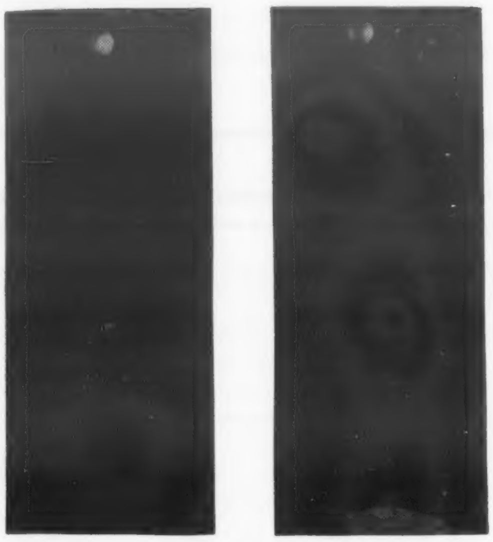
2. Silicone-alkyd enamels *($1\text{-}5 \times 10^9$ r)*

Except for some crosslinking, unbaked silicone-alkyd enamels appear to be little affected by 1×10^9 r of radiation. However, 5×10^9 r produces crosslinking and slightly degrades the unbaked coating.

Silicone-alkyd coatings not exposed to radiation but heated 50 hr at 500 F become completely discolored. These coatings experience partial destruction of the resin by oxidation. However, there is some evidence that radiation of 1×10^8 and 1×10^9 r rearranges the silicone-alkyd resin and provides it with more heat resistance. Coatings exposed to these radiation levels and to heat exhibit better film condition, abrasion resistance and flexibility than unexposed coatings. Exposure to 5×10^9 r, however, produces oxidation and crosslinking of the resin, and causes the coating to become powdery and brittle.

Heat exposure: None
Radiation exposure (r):

0 | 1 x 10^9



3. Alkyd enamels

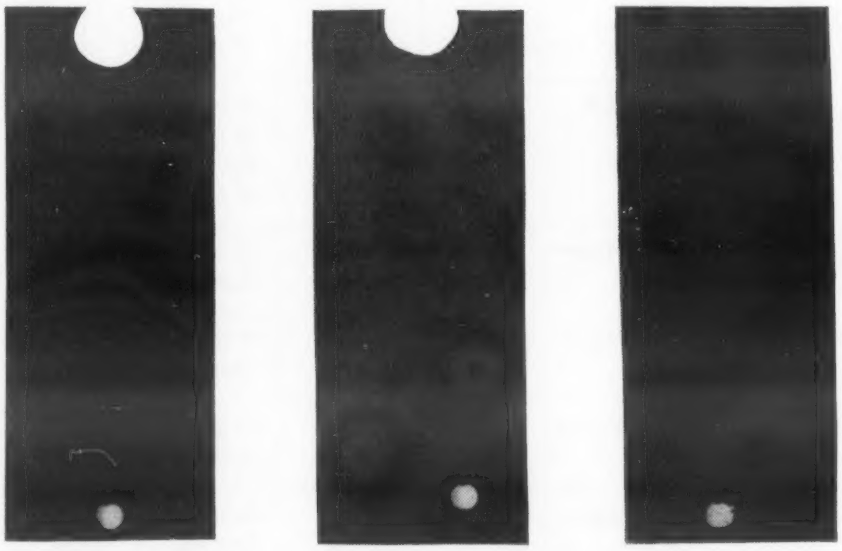
a. 40% phthalic anhydride, MIL-D-5557 (1-5 x 10^9 r)
b. 32% phthalic anhydride, MIL-E-7729 (7-10 x 10^8 r)

After exposure to 1 x 10^9 r both red and white 32% phthalic anhydride alkyd enamels become embrittled and change color. This embrittlement is probably caused by oxidation and crosslinking at the double bonds. Also, after exposure the white enamel exhibits a large increase in abrasion resistance and a large decrease in adhesion. The red enamel suffers only a slight decrease in adhesion after exposure.

In contrast to the red and white alkyd enamels, the black 32% phthalic anhydride alkyd enamel softens when exposed to 1 x 10^9 r. This increased softness manifests itself by decreased adhesion (see photo) and abrasion resistance, and by greater flexibility.

Heat exposure: 50 hr at 250 F
Radiation exposure (r):

0 | 1 x 10^9 | 5 x 10^9



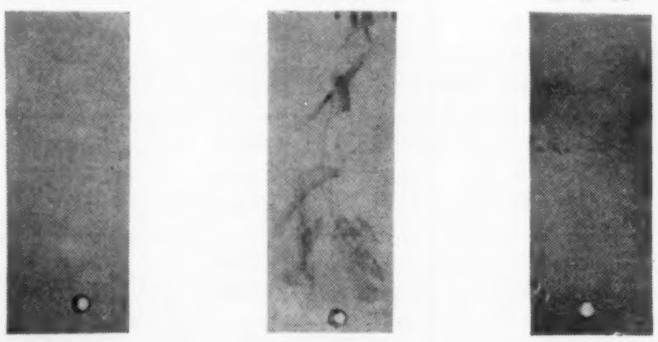
4. Epoxy coatings

(5-10 x 10^8 r)

Though not very evident from the photographs, the properties of epoxy coatings are severely degraded by radiation exposure (one exception: an increase in the abrasion resistance of unbaked coatings). The poor resistance of coatings to radiation is probably due to excessive crosslinking and/or degradation of the aliphatic portions of the chains. Also, the metal coating bond seems to be preferentially attacked, as evidenced by the marked decrease in adhesion after irradiation.

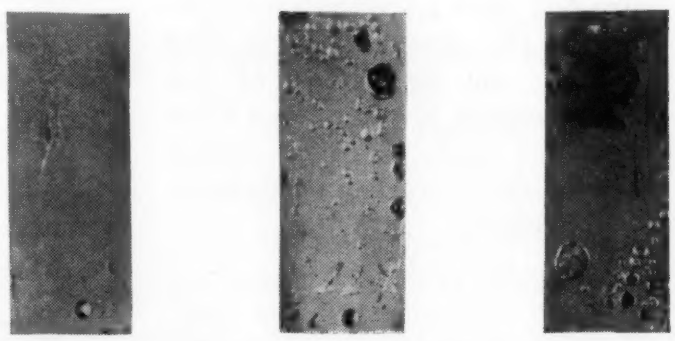
Heat exposure: None
Radiation exposure (r):

0 | 1 x 10^9 | 5 x 10^9



Heat exposure: 50 hr at 250 F
Radiation exposure (r):

0 | 1 x 10^9 | 5 x 10^9



5. Fluorinated vinyl coatings

A copolymer of trifluorochloroethylene and vinylidene fluoride (5-10 x 10^8 r)

This coating is usually fused to provide good adhesion. Exposure of unfused coatings to 1 x 10^9 r results in improved adhesion and abrasion resistance. However, increasing radiation produces crosslinking and bond-breaking degradation, and causes the coating to lose its good cohesion and corrosion resistance.

Increasing the radiation level to 5 x 10^9 r causes the unfused coating to blister and flake.

Coatings heated at 250 F show similar results except that adhesion starts to decrease at a lower radiation level. As shown, the coating begins to peel and flake at 1 x 10^9 r.

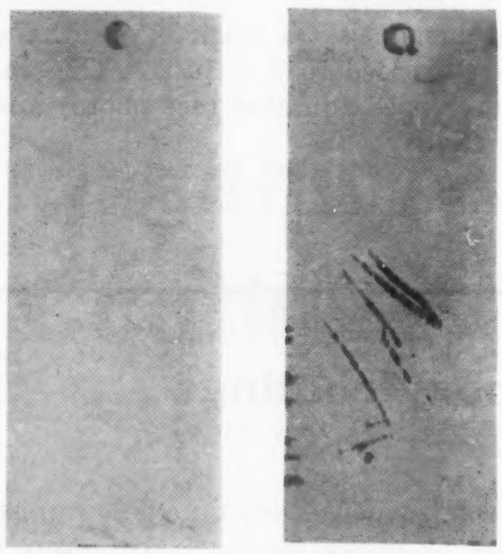
actor, the radiation consists primarily of fast and slow neutrons and gamma radiation.

Damage by fast neutrons is caused by the neutron ejecting a hydrogen nucleus (proton). Thus, the molecules become excited, are ionized, and finally break up. Slow (thermal) neutrons are generally captured by individual atoms such as hydrogen, chlorine and cobalt.

Gamma radiation (high energy photons) causes damage when the photon collides with an electron. The electron is ejected from the

Heat exposure: None
Radiation exposure (r):

0 | 1 x 10^9



6. Nitrocellulose lacquers

(5-7 x 10^8 r)

Extensive degradation of all physical and mechanical properties is exhibited by white nitrocellulose lacquers after exposure to 1 x 10^9 r. The coatings become quite porous and, as shown, their over-all condition is poor. The same exposure is not as damaging to red lacquers; these lacquers become brittle and nonporous after exposure but their adhesion increases.

With the exception of surface damage, the properties of the black lacquers are improved after exposure; such coatings exhibit a significant increase in toughness and adhesion.

PROPERTIES OF ORGANIC COATINGS AFTER

Coating Type, Color ↓	Bake Temp (50 hr), F	Radiation Exposure, 10^8 r	Taber Abrasion Resistance, cycles to failure	Flexibility[b]	Adhesion[c]
Phenolic—Blue[g]	None	0	—	—	—
	250	0	1490	Flaked	Good
		10	884	Flaked	Good
	500	0	867	Cracked	Good
		10	905	Cracked	Very good
Silicone-Alkyd Enamel—White	None	0	284	Good	Good
		1	288	Sl cracked	Good
		10	521	Sl cracked	Good
		50	657	Sl cracked	Fair
	500	0	146	Cracked	Fair
		1	176	Sl cracked	Good
		10	213	Good	Good
		50	163	Sl cracked	Poor
Alkyd Enamel (40% phthalic anhydride)—Black[h]	None	0	55	Sl cracked	Fair
		10	42	Good	Fair
Alkyd Enamel (32% phthalic anhydride)—Red[i]	None	0	138	Cracked	Fair
		10	146	Cracked	Fair
Alkyd Enamel (32% phthalic anhydride)—White	None	0	76	Cracked	Fair
		10	210	Cracked	Fair
Epoxy—Blue-Gray[j]	None	0	113	Good	Good
		10	138	Cracked	Fair
		50	400	Cracked	Fair
	250	0	877	Good	Good
		10	542	Cracked	Good
		50	357	Flaked	Poor
Fluorinated Vinyl—Aluminum	None	0	67	Good	Good
		10	705	Good	Fair
		50	82	Good	Fair
	250	0	229	Good	Good
		10	796	Good	Good
		50	119	Flaked	Poor
Nitrocellulose Lacquer—White[k]	None	0	196	Good	Good
		10	128	Flaked	Poor
Nitrocellulose Lacquer—Red	None	0	71	Good	Good
		10	84	Flaked	Fair
Nitrocellulose Lacquer—Black	None	0	30	Good	Good
		10	51	Good	Good

[a]Coatings applied to AZ31 magnesium alloy treated with Dow No. 7 chemical conversion coating.
[b]Determined by bending 0.02-in. panel over ⅜-in. mandrel.
[c]Tested with Arco Micro-Knife.
[d]Fraction of squares removed when a grid with lines 17 mils apart is cut with an Arco Micro-Knife.
[e]Exposure to 100% RH at 120 F.

atom and the photon rebounds and collides with other electrons. The net result is an excitation and ionization of the molecules which produces free radicals and ions. These molecular fragments then recombine with each other, with displaced electrons, and with oxygen from the air. As the result of this action polymers usually exhibit an increase or decrease in molecular weight and either become embrittled or more fluid.

The resistance of polymers to gamma radiation can be increased by increasing electron mobility and/or oxidation stability. In general, the molecules of an aromatic system have high electron mobility and are comparatively stable. In some cases, carbon black protects a polymer by increasing its oxygen stability.

EXPOSURE TO GAMMA RADIATION[a]

Fractional Vacancies[d]	Corrosion Resistance[e]		Reflectance, %[f]			
	Exposure, days	Extent of Blistering	400 mμ	500 mμ	600 mμ	700 mμ
—	—	—	7	6	8	25
0.42	4-12	Many	7	6	7	25
0.43	12	Many	7	7	6	23
0.49	4	Many	10	9	8	7
0.45	28	None	10	9	8	8
0.98	28	None	46	90	90	90
0.88	28	None	46	89	90	90
0.41	28	None	46	86	87	87
0.70	28	None	40	76	82	84
None	28	None	20	28	37	50
None	28	None	22	31	40	53
None	28	None	21	30	41	55
None	5	None	13	18	25	35
0.53	4	Many	4	4	4	4
0.60	4	Many	4	4	4	4
0.54	4	Many	5	5	17	45
0.56	4-5	Many	5	5	17	42
0.39	4	Many	42	84	82	79
0.73	4-5	Many	37	78	81	79
0.04	28	None	17	15	13	12
0.41	12	Slight	15	15	13	12
0.94	4-18	Many	11	14	17	16
0.02	28	None	15	15	13	12
0.32	12-18	Slight	12	13	13	12
0.95	4	Many	8	9	9	10
0.04	28	None	17	15	13	12
0.41	12	Many	15	15	13	12
0.94	4-18	Many small	11	14	17	16
0.02	28	Slight	15	15	13	12
0.32	12-18	Many	12	13	13	12
0.95	4	Many	8	9	9	10
0.54	4-5	Many small	46	79	77	74
0.25	28	Slight	24	52	68	71
0.65	28	None	5	5	13	41
0.43	28	None	5	5	12	38
0.50	5	Many small	5	4	4	4
0.33	28	Many small	5	4	4	4

[f]General Electric recording spectrophotometer.
[g]MIL-R-3043.
[h]MIL-E-5557. Applied over zinc chromate primer, MIL-P-6889, Type I.
[i]MIL-E-7729. Applied over zinc chromate primer, MIL-P-6889, Type I.
[j]MIL-C-4556.
[k]MIL-L-7178. Applied over zinc chromate primer, MIL-L-6889, Type I.

Effects of exposure

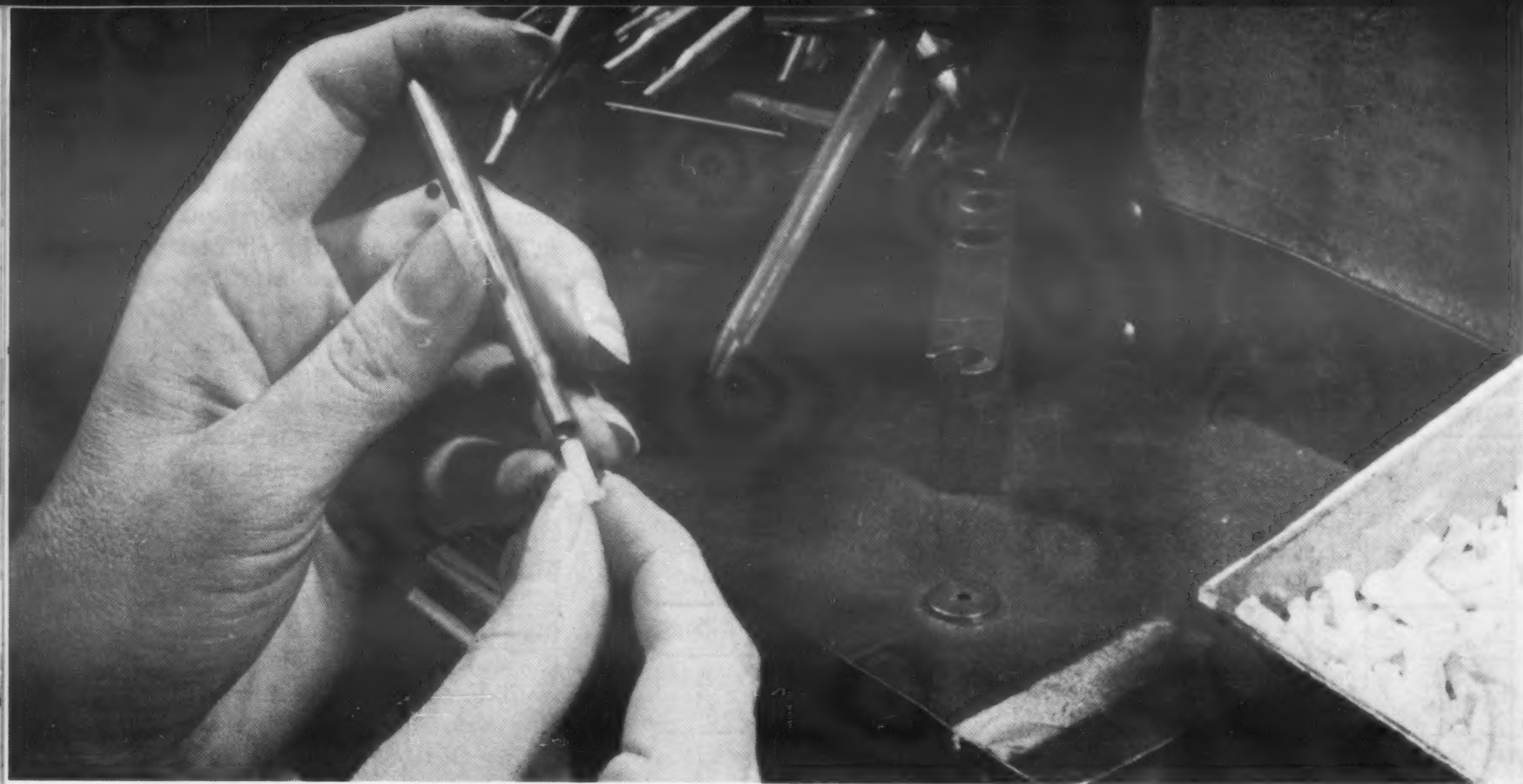
The resistance of organic coatings to radiation can be predicted to some degree from the data available on polymers and plastics. However, because of the complicating factors introduced by pigments, plasticizers and other coating ingredients, exact prediction of a coating's resistance to radiation can only be obtained by laboratory or field testing.

Of the coating systems described here, two—nitrocellulose lacquers and alkyd enamels—are widely used on today's aircraft. The remainder either are used to a limited extent or are being contemplated for future applications. All of these coating systems were applied to AZ31 magnesium alloy treated with a Dow No. 7 chemical conversion coating.

As shown in the accompanying table, the coatings were evaluated at three different radiation levels: 1×10^8, 1×10^9 and 5×10^9 roentgens. Controls were run on all coatings. Some coatings were exposed for 50 hr at 250 and 500 F following radiation exposure to measure the combined effects of radiation and heat.

A striking difference is noted when different pigments are used with the same resin. White titanium dioxide appears to accelerate radiation damage in nitrocellulose lacquers. Toluidine-red has little effect, whereas carbon black inhibits radiation damage.

A valid comparison of various coating systems that have been exposed to gamma radiation can be made only if the same type of pigmentation is used throughout. This conclusion is similar to that previously found for polyethylene.



Nylon pawl is inserted in ink cartridge.

Nylon Parts Lengthen Life of Ball Point Pen

by A. E. Simon, Jr., *Esterbrook Pen Co.*

■ Ball point pens are one of those prosaic consumer products of which almost everyone has an opinion as to what constitutes a good or bad design. Designers as well as consumers, however, are pretty much in agreement that a good pen must: 1) be reliable, and 2) not wear out. To meet these requirements careful attention must be devoted to both mechanical design and materials selection.

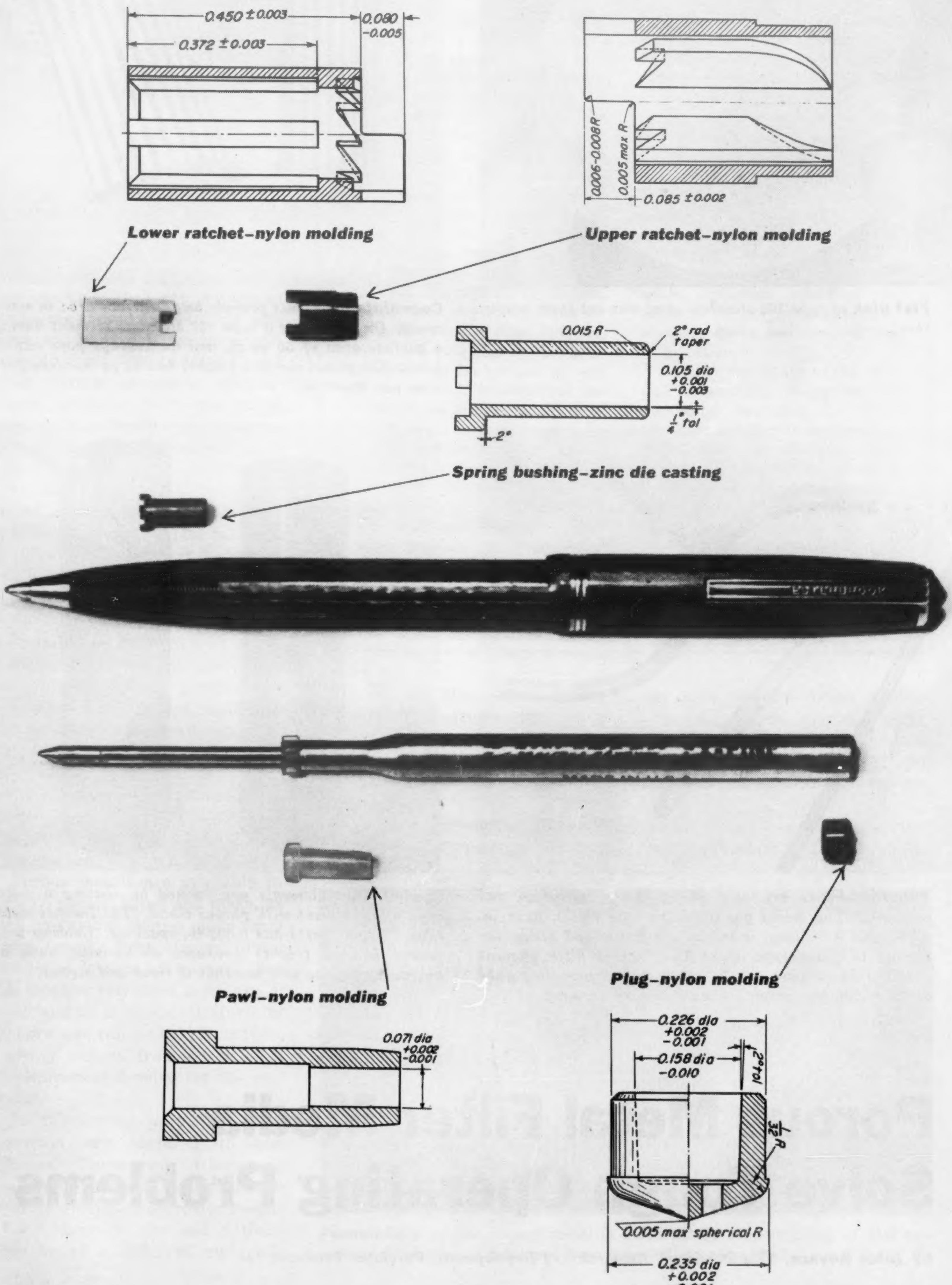
Wear in ball point pens is largely caused by the fact that most people usually pick up and hold a pen with the clip up. Constant use of the pen in this position causes excessive lateral wear on the ball seat or retainer and also causes poor ink distribution. To alleviate these problems it was decided to incorporate a rotating mechanism into the pen which rotates the cartridge and ball assembly 90 deg every time the assembly is retracted by the user.

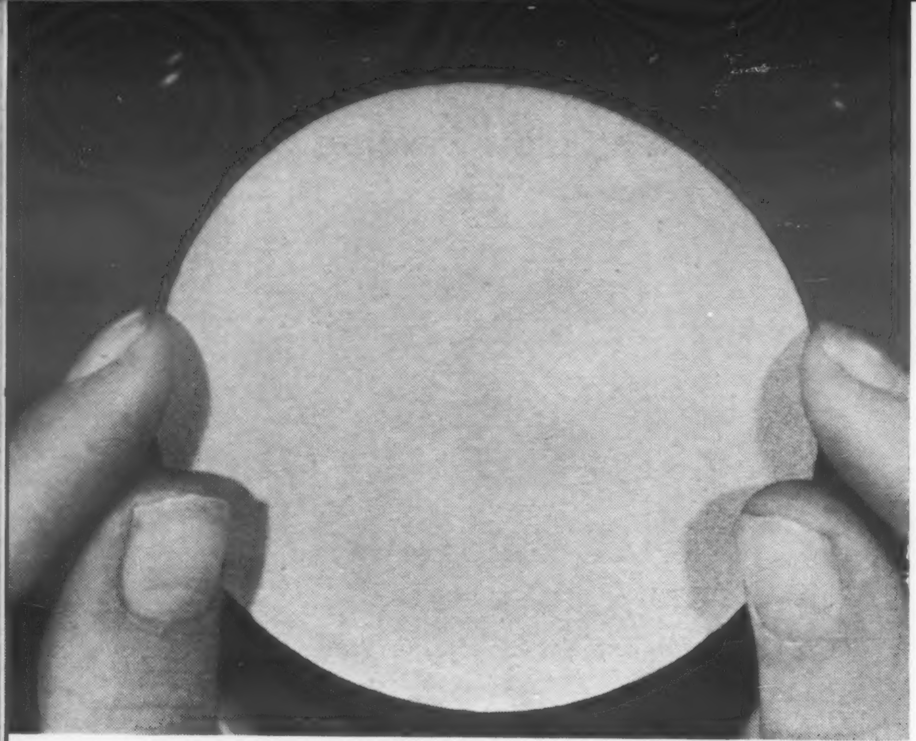
This rotary motion is imparted principally through the action of two ratchets, a pawl and a spring bushing. (These parts, shown on the opposite page, and other critical moldings for the pen are made by Gries Reproducer Corp.) Nylon was selected for the ratchets and pawl principally because of its high wear resistance, its low coefficient of friction and the fact that it does not require lubrication. The doubly tapered ears of the pawl are less than 0.01 in. high and are subject to considerable pressure since they have to slide along the teeth of the upper and lower ratchets each time the cartridge assembly is rotated. The so-called self-lubricating properties of these parts enable them to function smoothly with minimum effort and wear. One pen has gone through 800,000 test cycles—roughly equivalent to 50 years of use—with hardly any noticeable wear.

Since the spring bushing operates under less severe wear conditions, the designers were able to select the most economical material and production method available for this part: zinc die casting. Because of the close tolerances required (see sketches), these zinc parts—as well as the nylon parts—are produced in single cavity molds. Thus, although dimensions may vary slightly from nominal, these variations are always in the same direction and preclude the need for selective assembly.

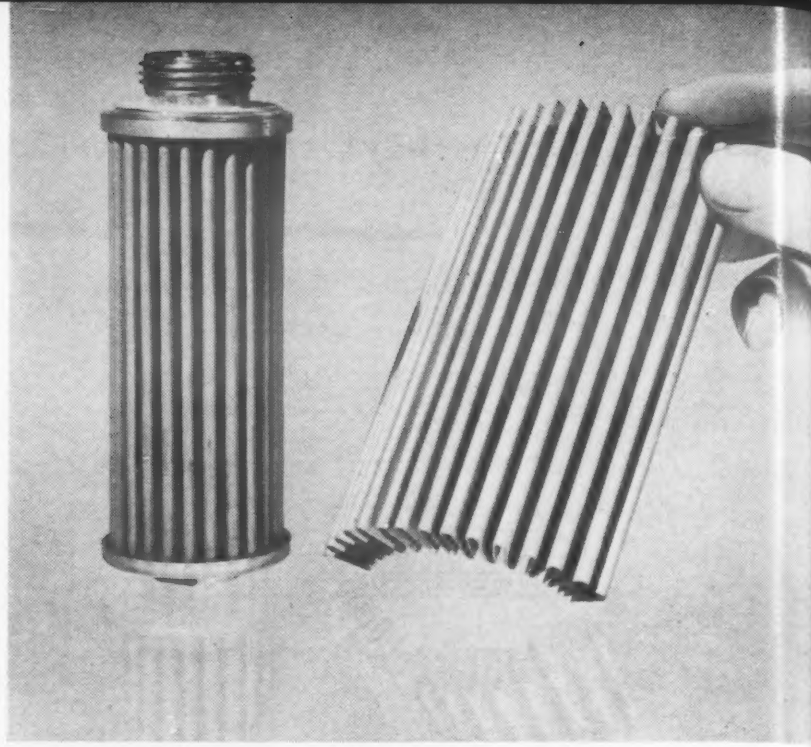
Two other nylon parts used in the pen are a spacer (not shown) and a refill plug. Nylon was selected for the plug principally because of its ink resistance and the fact that it could be dyed either red or blue to indicate the color of ink in the cartridge.

The key parts: four nylon moldings and a zinc die casting

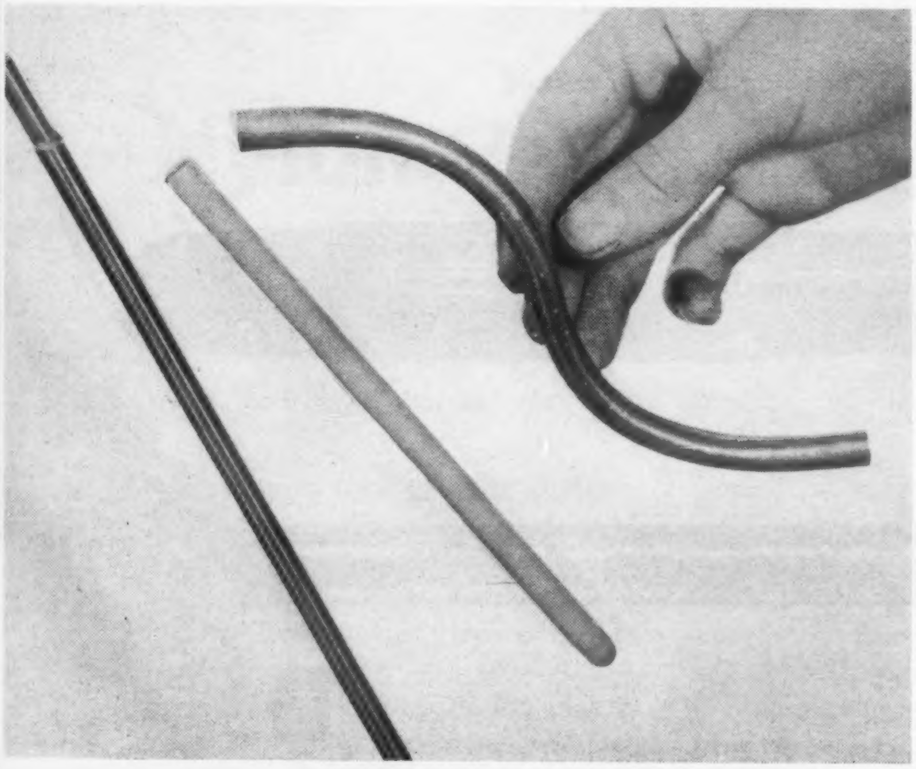




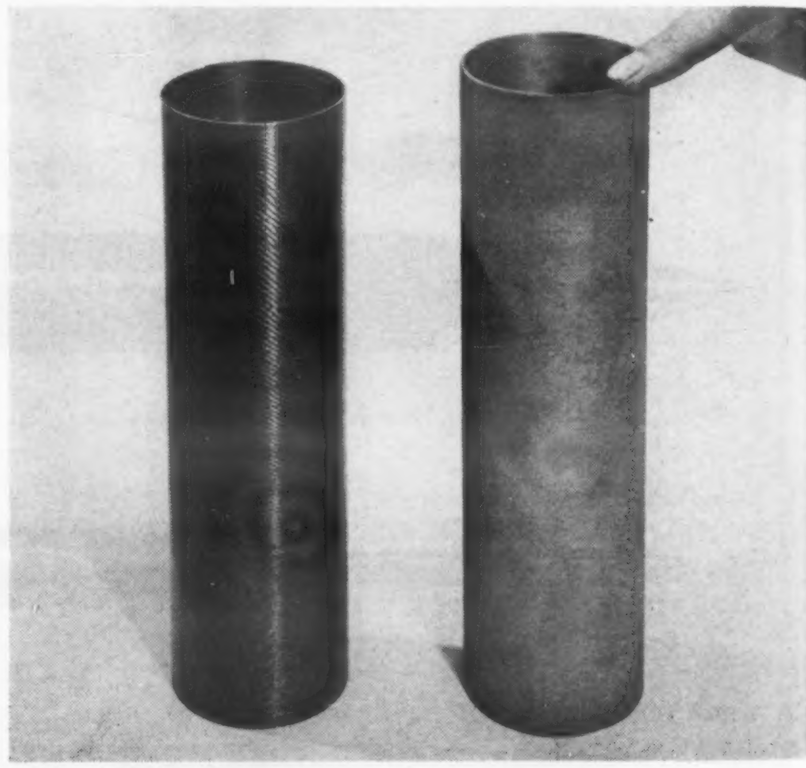
Flat disk *of type 304 stainless steel was cut from porous sheet.*



Convoluted *elements provide large surface area in small space. On the left is a type 347 stainless element having a surface area of 50 sq in. and an average pore size of 5 mu. The monel element (right) has 42 sq in. of surface area per linear in.*



Tubular *shapes are used for diffusion, filtration and sampling. The monel gas diffusion tube (left), 5/16 in. in dia and 9 in. long, is fused to a Kovar end fitting for sealing to glass apparatus. The Inconel filter element (center) has a pore size of about 2 mu. Sampling tube of 18-8 stainless (right) shows ease of forming.*



Coated *filter elements are formed by coating a metal edge filter element with porous metal. The Inconel metal edge element (left) has 0.003-in. spacings. Coating with porous Inconel (right) produces an element with an average pore size of 8 mu that is rigid and strong.*

Porous Metal Filter Media Solve Tough Operating Problems

by Jules Kovacs, *Vice President, Research and Development, Purolator Products, Inc.*

Here are applications where corrosion resistant metals of controlled porosity have proved useful in various forms.

■ Porous metal filter media were developed for service under operating conditions that are not suitable for the use of filter media such as cellulose, plastics or glass. For example, they can withstand pressures ranging from a low vacuum to 6000 psi, temperatures ranging from –420 to 1200 F, and most severe corrosive environments, provided the proper metal is used. Metallic elements are usually required for operating temperatures much above 400 F or for differential pressures exceeding about 100 psi.

Major applications, in addition to filtration, include separation of two liquids, gaseous diffusion, and gas-liquid and liquid-liquid contacting.

Materials and forms

Metallic filter units are made by sintering metal powders of controlled particle size to obtain the desired porosity and pore size. Metals are selected to meet specific service requirements and include all grades of stainless steel, nickel, monel, Inconel, Hastelloy, Durimet 20, bronze, nickel silver, gold and silver.

Porous metals are available in flexible sheets, tubes and disks, as well as various shapes made from these forms. Pore size of filters can be as low as 0.2 microns, but the most widely used sizes are 4, 8, 12 and 25 microns. Uniformity of pore size can be held to ±10%. Density ranges from 40 to 50% of theoretical density for the material.

In fabricating units, the filter elements are sintered to end fittings. These end fittings are usually of the same composition to provide maximum corrosion resistance. However, the end fittings may be of a different material; hydraulic oil filter elements for aircraft applications are made with a stainless steel porous section cemented to aluminum end fittings.

Applications

Originally developed for aircraft hydraulic systems, the porous units are now being used in chemical process, atomic energy, petroleum and similar industries for filtration, elimination of contamination and diffusion applications.

Filtration—The filtration potentialities of metallic filter elements

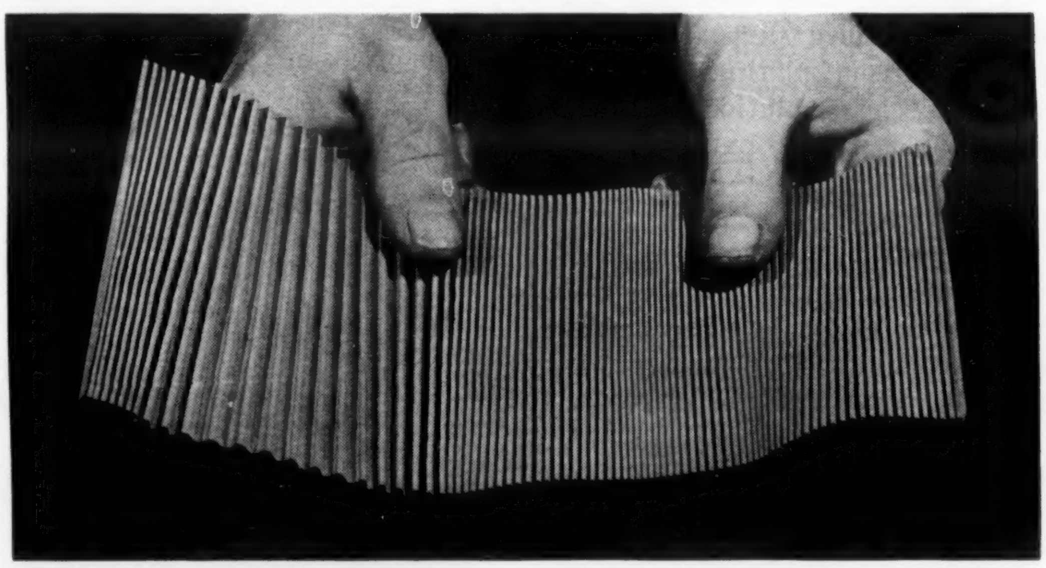
Advantages of Thin-Wall Materials

Although other methods have been used to produce porous metal filter elements, the Purolator method has certain advantages. Wall thickness can be varied from 0.015 in. up, the preferred thickness being about 0.030 in. By contrast, a porous metal sheet is available that can be produced as thin as 0.010 in., but the standard material ranges from about 0.030 to 0.060 in. thick. Thin wall construction has advantages over thick-wall construction in that: 1) surface, rather than depth, filtration occurs, 2) pressure drop is lower, 3) a thin-wall element is easier to clean by back-washing, and 4) service life is improved because there is less clogging of the pores.

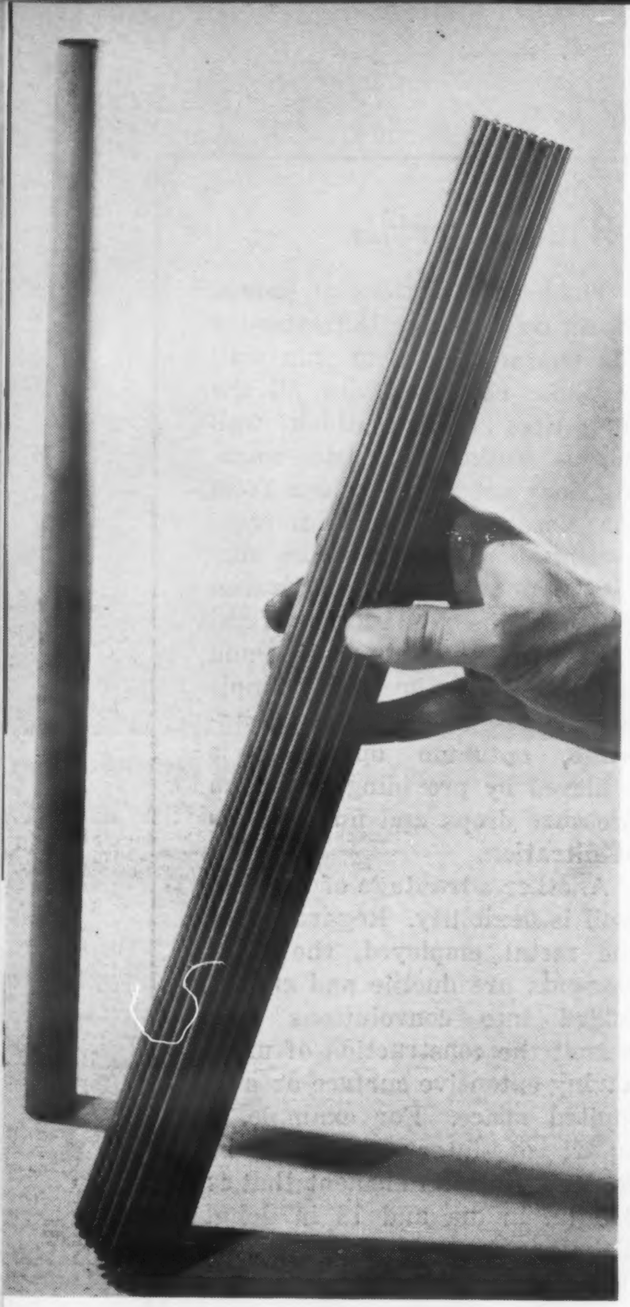
Since porous metal media are more expensive than cellulosic media, the cleanability of the element is extremely important. A thin wall section with uniform pores provides optimum filtration, yet can be readily cleaned by a simple rinsing and/or back-washing operation.

Thick wall sections of porous media do not have the extended life characteristics of thin wall sections. Fine particles fill the interstices of the thick wall porous sections and back-washing does not remove them from the close network of interconnecting pores. Hence, the surface type filtration mechanism prevents the contaminate from "filling up" these interstices and recleaning becomes a simple back-washing operation. Meanwhile, optimum operation is achieved by providing minimum pressure drops and fine degrees of filtration.

Another advantage of the thin wall is flexibility. Regardless of the metal employed, the filter elements are ductile and can be folded into convolutions that permit the construction of units having extensive surface area in limited space. For example, 6 sq ft of filter area can be squeezed into an element that is 3½ in. in dia and 18 in. long. Tubular elements can be bent into various simple contours.



Formability *of the porous metal is indicated by the flexibility of this convoluted filter element produced from type 302 stainless steel.*



__Variety of diameters__ is possible. The thin wall tube (left) is ⅞ in. in dia. Made of type 304 stainless, it has a pore size of 5 mm. The filter element (right) has a diameter of 1.75 in. and a surface area of about 1.5 sq ft.

are illustrated by five important applications:

1. Metallic filter elements are used to remove dirt and other particles from plating baths to assure a clean solution. For an acid copper plating bath, a Durimet 20 filter element gives excellent service.

2. Filtration of liquids at high temperatures usually requires metallic filter elements. The operation is complicated if the liquid is corrosive, since rates of corrosion increase with temperature. A metal must be highly resistant to the corrosive environment to be suitable for use as a filter because of the relatively large surface area exposed to the solution; careful selection is necessary. Thus, stainless steel type 302 is suitable for filtration of the hot alkali baths used for cleaning metal parts before plating, but might be completely unsuited to handling a hot acid solution.

3. Removal of oxide from molten sodium is required before introducing the sodium into a nuclear reactor system. Common filtration rates average 250 lb per hr per sq ft at a temperature of 235 F and a differential pressure of 20 psi. Stainless steel (type 304 or 347) filter elements with an average pore size of 5 microns are used in this operation.

4. Because of their strengths, porous metal filter elements can be used for high pressure applications that are often avoided because of handling difficulties. Filtration of a hot, corrosive condensible gas under high pressure is usually avoided by delaying the filtration until condensation has been completed and the pressure is reduced. Contaminants that may be insoluble in the gaseous phase may go into solution in the liquid and therefore not be removed by filtration. Such contaminants can be removed by filtering the gas.

5. At the other end of the temperature scale is filtration of liquid oxygen, helium, etc. These liquids have temperatures around -300 F and lower, and metallic filter elements are necessary. Glass or cellulosic media become so brittle at these low temperatures that shock or vibration cause fragmentation, and particles of the filter media break off.

6. Stack gases, process gas streams and heated air streams often carry contaminants that require removal. An example is the removal of finely divided particles of catalyst from the gaseous product of a petroleum catalytic cracking unit. Removal of the catalyst not only purifies the gas stream but also recovers the catalyst which can be regenerated and reused.

Prevention of contamination—An unusual application of porous metal is the lining of a pipeline to prevent corrosion products from entering a gas or liquid stream. In one application, carbon tubes were in use as a heat exchanger. The hot gas etched the tubes, carrying particles of carbon into the gas stream. A porous metal liner was used to prevent pickup of the particles, yet permit the gas to diffuse to the wall for proper heat transfer.

Separation of gases—Gaseous diffusers can be prepared by plating special metals upon porous metal elements. These diffusers can be used to separate components of gas streams because of the difference in the diffusion coefficients of various gases. For example, a nickel porous element, plated with palladium, can be used to separate hydrogen from a mixture of butane, butene and hydrogen. Also it is possible that diffusers may be developed to remove hydrogen from natural gas, thus offering a source of hydrogen for plant operation that would be cheaper and more readily available than the cylinders now in use.

Mixing—Porous metal can be used also to mix thoroughly two liquids or a liquid and a gas. Selection of a suitable pore size will provide for the proper introduction of the second material into the first and assure uniform mixing.

The metallic medium offers the advantages of heat transfer by conduction, large surface area, higher flow rates than ceramics (because of the greater density of a metal), and corrosion resistance. Porous media can be used as bubble caps where a gas is bubbled through the porous medium into a liquid layer. The fine bubbles allow intimate contact between the gas and liquid, hence a scrubbing action occurs. The same process applies to two immiscible liquids. Pellets of porous metal can replace saddles or rings.

Editor's Note

A previous article on porous metal was published in MATERIALS & METHODS, Apr '55, p 98.

Spi
eth

E. I. du Pont de Nemours & Co.

Spin welding *is one effective method of joining thermoplastics. Polyethylene, acrylic and nylon products are shown below.*

Materials
in Design Engineering

Manual No. 145
January 1958

Joining and Fastening Plastics

by Malcolm W. Riley,
Associate Editor,
Materials in Design Engineering

This survey, which covers the four basic methods of joining plastics, should help you considerably in the design of assemblies containing plastics parts. It tells you the most suitable plastics, the bond characteristics, design considerations and application techniques for joints made by:

- *Solvent cementing*
- *Adhesive bonding*
- *Thermal welding*
- *Mechanical fastening*

Selection Factors

There are four basic methods of joining plastics: 1) solvent cementing, which provides a *co*hesive bond consisting essentially of the parent material, and thus having properties similar to those of the parent material; 2) adhesive bonding, which provides a *co*hesive glue line, each side of which *ad*heres to the bonding surface of the parts to be joined; 3) thermal welding, which provides a fusion bond consisting of the materials being joined; and 4) mechanical fastening, which provides a mechanical lock between the parts being joined.

In approaching the problem of selecting the best joining method for a particular application several factors must be considered:

1. Chemical nature and form of the plastics to be joined.

Because of the basic differences between thermoplastic and thermosetting plastics an initial screening by plastics type can eliminate some of the joining methods, narrowing the choice. The accompanying table indicates the materials that can be joined by each method, as well as the primary characteristics of the joints produced by each method.

2. Desired characteristics of the bond as dictated by the service conditions under which it must function.

The nature of the desired bond is dependent on the service conditions under which it must operate. Will it be stressed? Will it be exposed to heat or chemical environments? Must it be flexible? Must it permit movement between the parts?

In discussing the nature of bonds between plastics, few mechanical property data are useful because of the dependency of mechanical properties on 1) the specific types and forms of materials being joined, 2) the way in which the joint is produced, and 3) the design configuration of the specific joint.

The effects of environmental conditions such as heat and chemicals differ. On bonds produced by solvent cementing and thermal welding, environmental effects are principally the effects upon the parent plastics (though in some cases chemicals may cause crazing in cemented joints, as explained later). Joints produced by adhesive bonding or mechanical fastening, on the other hand, are subject to the effects of environment on the particular adhesive selected (though in many cases exposure may be only at the edge of a glue line) or the fastener used.

3. Economics in obtaining the bond.

The best bond is the bond which meets the design requirements most economically. Costs for each joining method can vary widely, depending on the design of the part, the requirements of the bond and the volume of production. Specific costs must be worked out for each joining problem.

Solvent Cemented Joints

Solvent cementing makes use of the fact that some thermoplastics are soluble in common solvents; thus the process can be used to join only certain thermoplastic resins. The resins best suited to solvent cementing are the amorphous or less crystalline resins, such as acrylics, polystyrenes, cellulosics and some vinyls. The more crystalline plastics, such as nylon and polyethylene, are less soluble and are better joined by other methods.

The process

The process involves 1) softening the bonding areas of the plastics with a solvent or solvent mixture, 2) fusing the softened areas with light pressure, and 3) permitting the solvents to evaporate, leaving a joint consisting essentially of the parent plastics. Strength of such a bond is similar to the strength of the parent plastics.

Selecting the cement — There are two basic types of cements: 1) solvent cements, which consist entirely of a solvent or a mixture of solvents, and 2) dope or bodied cements, consisting of solvents in which small quantities (usually 10-15%) of the parent resin have been dissolved, either to provide better application viscosities or to compensate for inconsistencies in the mating surfaces.

Two characteristics of solvents are critical in selecting the proper cement. These are: 1) solubility parameter, which determines the specific types of solvents in which each resin is most soluble, and 2) boiling point of the solvent, which determines the speed with which a bond is formed.

A resin dissolves best in a solvent whose solubility most closely approaches its own. By matching solubility parameters the engineer or designer can select the solvent or mixture of solvents which can best be used to join the plastics he is working with.

The boiling point of a solvent indicates the speed with which it evaporates and thus the speed with which a bond is formed. Low boiling solvents evaporate rapidly, and may cause blushing or crazing with certain plastics. High boiling solvents evaporate more slowly, and are usually mixed with low boiling solvents to control the speed of evaporation. The ideal combination of solvents in a cement provides the most rapid evaporation rate commensurate with freedom from blushing or crazing.

Application techniques — Re-

CHARACTERISTICS OF JOINING METHODS

Method ↓	Plastics To Be Joined	Joint Characteristics	Cost Factors[a]
Solvent Cementing	Most suitable for more amorphous and soluble thermoplastics such as acrylics, cellulosics and polystyrenes. Not generally useful for more crystalline, insoluble thermoplastics, such as polyethylene, nylon and fluorocarbons. Cannot be used for thermosets	Cohesive joint consisting essentially of parent materials. Joint properties similar to those of parent material	1. Solvents 2. Fixtures and assembly labor
Adhesive Bonding	Suitable for all plastics. Generally not used for joining thermoplastics suitable for solvent cementing	Adhesive joint, characteristics of which depend on 1) type of adhesive, 2) compatibility with adherends, 3) form of the adherends, e.g., film, sheet, molding and foam, and design of joint	1. Adhesive 2. Facilities and labor for applying adhesive 3. Facilities for applying heat and pressure (in most cases)
Thermal Welding	Suitable for virtually all thermoplastics, though particularly useful for joining the more crystalline types such as polyethylene, PVC, nylon. Cannot be used for any thermosetting plastics	Fusion joint consisting primarily of parent materials. Since fusion is not complete in all cases, strength may be less than that of parent material	1. Method of application of heat, i.e., gas or electric gun, heated tool or heat sealing equipment, induction heating equipment, machine shop facilities for spinning 2. Labor and facilities for assembling and completing weld
Mechanical Fastening	Suitable for all plastics materials, depending on allowable stress configuration in the joint	Either purely mechanical lock at location points of fasteners or frictional fit	1. Fasteners and labor in installing, or 2. Facilities for applying pressure (for press fit) or heat (for swaging and shrink fit) and labor in assembling

[a]These factors must be considered. Quantitatively they may vary widely in each specific case.

gardless of the type of cement used, the following precautions should be observed in order to obtain optimum bonds: 1) bonding surfaces should be clean and dry, 2) bonding surfaces should be smooth and aligned as perfectly as possible to minimize stress points and ensure complete bonding across the interface, 3) the cement must be active enough and applied in such a manner to soften the bonding surface deeply enough so that when pressure is applied a degree of flow occurs at every point on the interface, 4) the composition of the cement should be such that it dries completely and at a rate which will not cause objectionable blushing or crazing, 5) pressure must be applied until the joint is set to the extent that there is no movement when pressure is released, 6) subsequent operations such as sawing, sanding, filing or other finishing operations must be delayed until the joint has become completely hard, and 7) care must be taken that the vapors from the solvents do not etch the parent plastic.

Cements may be applied directly to the surfaces to be bonded, or they may reach the interface by capillary action after the parts are assembled.

When applying directly to the bonding surface, the following methods are commonly used:

1. Brushing directly on areas to be bonded.
2. Soaking or dipping the bonding areas in cement.
3. Applying by contact with a felt pad which acts as a wick when placed in the solvent pan.
4. Spraying the cement with a small conventional spray gun.

Cements can also be applied to the interface of assembled parts with a hypodermic needle or medicine dropper. Capillary action then moves the cement throughout the interface. Where bond areas are large, small wires temporarily inserted in the joint facilitate complete wetting of the bonding area.

The plastics

The following discussion provides general recommendations for types of solvents that should be used for cementing various types of thermoplastics. It also points out some of the problems in solvent cementing specific plastics.

Cast acrylic sheet—Cast acrylic sheet can be solvent cemented more readily and successfully than can molded or extruded acrylics, since the latter tend to dissolve, or "unmold," before building up a sufficient "cushion" of softened area. Thus the materials are treated separately here.

Cast acrylic sheet can be bonded to itself in a cemented joint that closely approximates in transparency a single piece of the material. The joint will not be invisible because of optical distortions introduced by thickness variations at the joint, and because of a visible change in the index of refraction at the joint. Also, the color of cemented areas in colored acrylic sheet, may vary

TABLE 1—EFFECT OF OUTDOOR EXPOSURE ON SOLVENT-CEMENTED CAST ACRYLICS[a]
(Tested at 74 F)

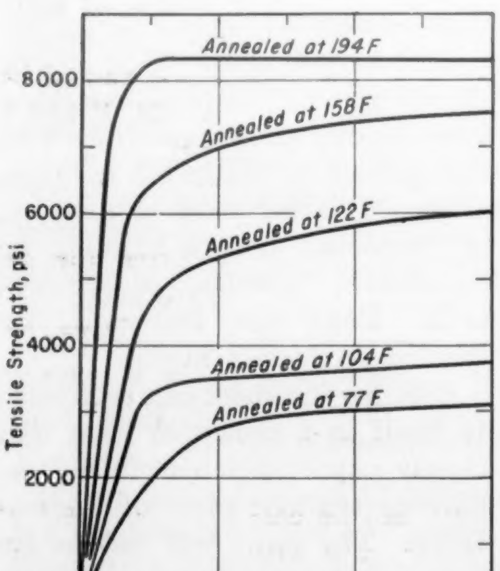
Anneal Cycles[b]	Average Tensile Strength, psi	
	Unexposed	Exposed[c]
7 Days, 77 F	3000	3500
24 Hr, 158 F	6000	4600
24 Hr, 194 F	6300	5400

[a]Bonds formed with 60:40 methylene chloride: methyl methacrylate monomer. Acrylic material is Plexiglas II bonded to itself.
[b]Annealed at indicated times and temperatures after assembly.
[c]Two years outdoor exposure.
Source: Rohm & Haas Co.

from the color of the sheet when the points are viewed under certain light conditions.

Because of residual stresses set up during machining and fabricating, acrylics are susceptible to crazing upon application of solvent cements. Parts should be annealed as soon as possible before cementing (preferably not more than 24 hr before cementing) and 4 hr or more after cementing.

Strength of the joint will vary according to the cement and technique used. Joints having room temperature strengths of approximately 75% of the tensile strength of the parent material have been



***Typical tensile strengths** of solvent cemented bonds in cast acrylic sheeting after annealing the bond at various temperatures.* (Rohm & Haas Co.)

made. The accompanying graph shows tensile strengths obtained with a typical cement and various annealing temperatures. Good resistance to outdoor weathering can also be provided. Table 1 shows effects of weathering on tensile strengths of joints.

Speed of evaporation of solvent cements from acrylics must be controlled rather carefully because of the tendency of the material to craze. Typical recommended solvent cements are given in Table 2.

Where higher viscosity cements are desirable from the application standpoint, dope cements can be prepared by adding to the solvent mixture clean acrylic chips, shavings or molding powder. Such viscous cements act primarily as carriers for the solvent, since solids contents are usually not sufficient to fill in discrepancies in mating parts.

(So-called polymerizable cements often used to bond cast acrylics should not be confused with solvent or dope type cements. They are actually adhesives, consisting of methyl methacrylate polymer, methyl methacrylate monomer, a catalyst and promoter. They cure by polymerization, and the bond is obtained through adhesion of the cement to the adherends.)

Molded acrylics—Although molded acrylics are more difficult to cement than cast acrylics, joints can be successfully produced. Because of the tendency of molded acrylics to dissolve and unmold in solvents, the soak method commonly used to apply cements to cast acrylics cannot be used. Cements can be applied to molded acrylics by dip, brush or capillary techniques.

Recommended solvent and dope type cements are given in Table 2.

Polystyrenes (including polymethylstyrenes) — Styrene polymers are soluble in a wide variety of organic solvents. Styrene-acrylonitrile copolymers, because of their better chemical resistance, are soluble in fewer solvents than polystyrene. Since polystyrenes have relatively low elongations, crazing is one of the major problems associated with solvent cementing. Low boiling solvents provide rapid-setting bonds, but are most likely to cause crazing. Higher boiling solvents provide slower-setting bonds, but the bonds resist crazing for longer periods of time. Table 3 lists low, medium and high boiling solvents for polystyrene with the time before appearance of crazing.

Low boiling solvents are low in cost and are generally satisfactory when used with opaque polystyrenes or where the joint is inconspicuous. They should not be used where the mechanical requirements of the part preclude the occurrence of crazing and its deleterious effects on mechanical properties.

Medium boiling solvents provide an effective compromise between rate of drying and occurrence of crazing. They cannot be used to bond parts requiring optical clarity for extended periods of time.

High boiling solvents can provide craze-free joints for periods of at least two years and in many cases much longer, depending on the service conditions. When high boiling solvent cements are used, the addition of up to 70% methylene chloride or trichloroethylene speeds up drying without seriously contributing to the tendency to craze.

In general, where optical clarity or maximum mechanical properties are not mandatory, solvents in the boiling range of 170 to 250 F provide satisfactory drying time, good sealing and high bond strength.

Dope-type solvent cements are used to provide 1) more viscous adhesives, 2) better water or air tight seals, and 3) improved bonds between styrene and other materials, such as wood or cloth. One materials supplier recommends making dope cements by mixing 10-15% of styrene molding material with methylene chloride for fast setting bonds, with trichloroethylene for medium-fast setting bonds, and with perchloroethylene for medium setting bonds.

Cellulose acetate, butyrate and nitrate—Cellulose acetate, cellu-

Solvent cements for thermoplastics

TABLE 2—RECOMMENDED TYPICAL SOLVENT CEMENTS FOR ACRYLICS[a]

Composition	Remarks
CAST ACRYLICS	
Methylene Chloride (60%), Methyl Methacrylate Monomer (40%), Hydroquinone (0.006% by wt)	Maximum joint strength; good weathering resistance
Methylene Chloride (90%), Diacetone Alcohol (10%)	Medium joint strength; quick setting
1, 1, 2-Trichloroethane (vinyl trichloride)	Low tensile strength; easy to use
Ethylene Dichloride	Medium strength joint; quick setting; easy to use
Methylene Chloride	Medium joint strength; extremely rapid setting; joints apt to be cloudy
MOLDED ACRYLICS	
Methylene Chloride (50%), Denatured Alcohol SD-30 (50%), Acrylic Molding Powder (15% by wt)	For both outdoor and indoor use
Methylene Chloride (60%), Methyl Methacrylate Monomer (40%), Benzoyl Peroxide Catalyst (2.4 gm at 50% peroxide strength per lb cement)	For both outdoor and indoor use
Methylene Chloride (50%), Glacial Acetic Acid (50%), Acrylic Molding Powder (15% by wt)	For both outdoor and indoor use
Methylene Chloride (70%), Methyl Methacrylate Monomer (20%), Glacial Acetic Acid (10%)	For indoor exposure only
Methylene Chloride or Ethylene Dichloride	For indoor exposure only

[a]Compositions given by volume except as otherwise noted.
Source: Rohm & Haas Co.

TABLE 3—SOLVENTS FOR POLYSTYRENE

Solvent	Boiling Point, F	Time to Craze, months
FAST DRYING		
Methylene Chloride	104	½
Carbon Tetrachloride	170	½
Ethyl Acetate	170	¾
Benzene	176	¾
Methyl Ethyl Ketone	176	¾
Ethylene Dichloride	183	¾
MEDIUM DRYING		
Toluene	232	1
Perchloroethylene	250	1
Ethyl Benzene	276	4
Xylenes	280–291	4
Diethyl Benzene	365	12
SLOW DRYING		
Mono-Amyl Benzene	396	>20
Ethyl Naphthalene	495	>48

Source: *Plastics Engineering Handbook* of the Society of the Plastics Industry, Reinhold Publishing Corp., 1954.

TABLE 4—SOLVENT CEMENTS FOR ACETATE AND BUTYRATE

COMMON SOLVENTS (acetate and butyrate)[a]

Methylene Dichloride (106)	Isopropyl Acetate (194)[b]	Cellosolve (275)[b]
Acetone (135)	Nitro Methane (216)	Methyl Cellosolve Acetate (293)
Methyl Acetate (140)	Dioxane (216)	Ethyl Lactate (311)
Chloroform (142)[b]	Nitro Ethane (239)	Cylohexanone (313)
Ethyl Acetate (171)	Methyl Cellosolve (257)[b]	Diacetone Alcohol (331)
Methyl Ethyl Ketone (176)	Butyl Acetate (259)[b]	Butyl Lactate (385)[b]
Ethylene Dichloride (183)[b]		

SOLVENT CEMENT MIXTURES

Acetate to Acetate	Butyrate to Butyrate
1. Acetone (70%), Ethyl Lactate (30%)	1. Acetone (70%), Methyl Cellosolve Acetate (30%)
2. Ethyl Acetate (30%), Acetone (40%), Ethyl Lactate (30%)	2. Butyl Acetate (80%), Butyl Lactate (20%)
3. Acetone (70%), Methyl Cellosolve Acetate (30%)	3. Acetone (30%), Butyl Acetate (50%), Methyl Cellosolve Acetate (20%)

[a]Boiling point in °F given in parenthesis. [b]Solvents for butyrate only.
Source: Tennessee Eastman Co.

lose acetate butyrate and cellulose nitrate are grouped here because of similarities in both the cements used and the quality of the bonds obtainable with the materials. The materials are soluble in a wide variety of solvents, and joints of excellent quality can be obtained. Acetate should not be solvent cemented to butyrate; a nitrocellulose-base adhesive should be used for such joints.

There is little if any danger of plasticizer migration from butyrate (particularly in the harder flow grades) to other types of plastics. In proper formulations butyrate can be solvent cemented to acrylics, nitrocellulose and ethyl cellulose. On the other hand, plasticizers present in acetate are active for certain types of plastics and can migrate, causing crazing, softening or tackiness. Plasticizers used in acetate have a strong tendency to cause crazing of polystyrene and acrylics. All assemblies of these materials should be tested for crazing at 100 F and a minimum of 80% RH.

Table 4 lists solvents for both acetate and butyrate, and recommended solvent mixtures for cementing acetate to acetate and butyrate to butyrate. Dope cements can be prepared by mixing about 10% of the parent resin in the solvent mixtures.

Cellulose propionate—Propionate can be cemented to itself or to butyrate with a variety of solvent cements. These solvents, however, cannot be used for cementing propionate to acetate or ethyl cellulose; dope cements should be used.

The following solvents are

Celanese Corp. of America

Cellulosics *and other relatively noncrystalline plastics can be solvent cemented to provide strong watertight bonds.*

recommended for bonding propionate to itself or to butyrate: 1) rapid setting — acetone, methyl alcohol and ethyl acetate, 2) medium setting—methyl Cellosolve and mesital oxide, and 3) slow setting—methyl Cellosolve acetate, ethyl lactate and diacetone alcohol. These mixtures can be mixed in turn to provide specific set times desired. Again, too rapid setting may cause blushing.

Ethyl cellulose—Ethyl cellulose can be cemented to itself readily, providing strong bonds. The most common solvent cements for the material are mixtures of 1) toluene and alcohol, 2) ethyl acetate and alcohol, and 3) butyl acetate, toluene and alcohol. Dope cements are also common.

Polyvinyl chloride and copolymers—PVC is relatively inert to organic solvents and thus is difficult to join by solvent cementing. It lends itself more readily to thermal welding. PVC-acetate copolymers can be solvent cemented more readily because of the higher solubility of the acetate portion of the copolymer. In general, the greater the proportion of acetate the more readily the copolymer can be solvent cemented. The addition of plasticizers to copolymers further improves their cementability. Even when highly plasticized, however, high acetate copolymers do not provide as good bonds as do other resins such as the cellulosics.

Copolymer resins are most rapidly dissolved by ketone solvents, such as acetone, methyl ethyl ketone and methyl isobutyl ketone. The cyclic ketones, such as cyclohexanone, form solutions of the highest solids content, but are extremely high boiling solvents, resulting in slow drying and prolonged tackiness. They are used only for copolymers of high molecular weight and for straight PVC polymers.

Mixtures of ketones and aromatic hydrocarbons have a more rapid softening action than do ketones alone. Additions of aliphatic hydrocarbons and alcohols are sometimes advantageous.

Embrittlement by the solvent is one of the most troublesome factors in the bonding of rigid PVC or copolymer sheets by solvent cements. This phenomenon is probably due to molecular orientation and strain release occurring when the solvent is applied. Two ways of minimizing such embrittlement are: 1) using mixtures of less powerful solvents, and 2) using dope cements. The less powerful solvents evidently do not penetrate the material rapidly enough to cause embrittlement; similarly, the higher viscosity of dope cements apparently minimizes solvent penetration.

Other thermoplastics — Most other thermoplastics, because of their low solubility, do not lend themselves to solvent cementing, except for water soluble resins such as polyvinyl alcohol and polyethylene oxide, which can be cemented to themselves with water.

Fluorocarbon resins are inert to virtually all solvents. Nylon has low solubility in organic solvents and is not normally joined by solvent cements, though one proprietary cement trademarked Nylaweld FX-1 is said to provide strong and flexible joints. Polyethylenes are extremely inert and solvent type cements are ineffective. Polyvinylidene chloride cannot be solvent cemented with the same strength of bond as can other thermoplastics.

Adhesive Bonded Joints

Adhesive bonding is probably the most versatile of the plastics joining methods in the types of materials that can be bonded and the variety of service conditions for which a satisfactory bond can be developed. Adhesive bonding is used for joining: 1) thermosetting plastics to themselves, to other thermosets, to thermoplastics, or to other engineering materials, and 2) thermoplastics (generally those not soluble in common solvents) to themselves, to other thermoplastics, to thermosets, or to other engineering materials.

The problem of selecting and specifying an adhesive is extremely complex. There is an overwhelming number of adhesives available today, each of which may be a complex combination of various base materials, solvents, catalysts, plasticizers and other ingredients. Each of these adhesives may be modified to suit specific design needs. Determination of the proper adhesive depends on: 1) type and form of the plastics materials being joined, 2) service requirements of the bond, 3) method of application most effective and economical, and 4) curing limitations. The curing limitations are imposed by the needs of the particular adhesive, the characteristics of the plastics being joined, the production requirements, and the facilities of the specific plant.

New and old adhesives

A few of the most important and fairly recent developments in adhesives are:

1. Epoxy resin-based 100% solids adhesives—Since they are solvent-free they will not attack any soluble resin. They provide high strength bonds at room temperature, though oven cures speed setting and provide higher strengths and higher heat resistance. They provide the highest available block tensile and shear

TABLE 5—ADHESIVES REFERENCE CHART[a]

	Plastic → ↓	Acrylic	Cellulose Acetate	Cellulose Acetate Butyrate	Cellulose Nitrate	Ethyl Cellulose	Nylon	Polyethylene	Polystyrene	Fluorocarbon	Vinyl	Vinylidene Chloride	Melamine	Phenolic	Polyester	Urea
THERMOSETTING PLASTICS	Urea	5, 10	5, 10	5, 10	5	5, 10	1, 2, 3, 5, 6, 10	1	5	5	3	3	1, 5, 6, 7, 10, 11, 12	1, 5, 6, 7, 10, 11, 12	1, 5, 6, 7, 11, 12	1, 5, 6, 7, 10, 11, 12
	Polyester	3, 5, 9	5, 9	5, 9	5, 9	5, 9	1, 3, 5, 6	1	3, 5, 9	5	1, 3, 9	3, 9	1, 3, 5 6, 7, 12	1, 5, 6, 7, 9, 12	1, 5, 6, 7, 11, 12	
	Phenolic	1, 3, 5, 6, 9, 10, 11	1, 5, 6, 9, 10	1, 5, 6, 9, 10	1, 5, 9	1, 5, 9, 10	1, 3, 5, 6, 10	1	1, 3, 5, 9	5	1, 3, 9	1, 3, 9	1, 3, 5, 6, 7, 10, 11, 12	1, 5, 6, 7, 9, 10, 11, 12		
	Melamine	3, 5, 10	5, 9, 10	5, 10	5, 10	5, 10	1, 3, 5, 6	1	3, 5, 9	5	3	3	1, 3, 5, 6, 7, 9, 10, 11, 12			
THERMOPLASTICS	Vinylidene Chloride	1, 3, 9	1	1	1, 9	1, 9	1, 3	1	1, 9	1	1, 3, 9	1, 3, 9				
	Vinyl	1, 3, 9	1, 3, 9	1, 9	1, 9	1, 9	1, 3	1	1, 9	1, 5	1, 3, 9					
	Fluorocarbon	5	1, 5	1, 5	1, 5	1, 5	1, 5	1, 5	1, 5	1, 5						
	Polystyrene	1, 5, 9	1, 5, 9	1, 5, 9	1, 5, 9	1, 5, 9	1. 3, 5, 9	1, 5, 9	1, 5, 9							
	Polyethylene		1	1	1	1	1	1, 3, 9								
	Nylon	1, 3, 5, 9, 10	1, 3, 5, 9, 10	1, 3, 5, 9, 10	1, 3, 5, 9	1, 3, 5, 9, 10	1, 3, 5, 6, 10, 11									
	Ethyl Cellulose	1, 5, 9, 10	1, 5, 9, 10	1, 5, 9, 10	1, 5, 9	1, 5, 9, 10										
	Cellulose Nitrate	5, 9, 10	5, 9, 10	5, 9, 10	5, 9											
	Cellulose Acetate Butyrate	1,5, 9, 10	1, 5, 9, 10	1, 5, 9, 10												
	Cellulose Acetate	1, 5, 9, 10	1, 5, 9, 10													
	Acrylic	1, 5, 9, 10, 11														

KEY TO CHEMICAL TYPES OF ADHESIVES

1—Synthetic rubber or thermoplastic resin combined with thermosetting resin
2—Natural rubber
3—Synthetic rubber
4—Reclaimed rubber
5—Epoxy
6—Phenol formaldehyde
7—Urea formaldehyde
8—Melamine formaldehyde
9—Synthetic thermoplastic resins
10—Resorcinol formaldehyde
11—Furane
12—Polyesters

[a]This chart indicates only *chemical* types of adhesives which can be used to join the plastics indicated in the vertical column to the plastics indicated in the horizontal column. No other design considerations are calculated.
Source: *Plastics Engineering Handbook* of the Society of the Plastics Industry, Reinhold Publishing Corp., 1954.

strengths, but relatively poor peel strengths unless extensively compounded.

2. Contact bond adhesive, such as solvated neoprene types—These adhesives, used extensively for decorative plastics laminates and plastics counter tops, are applied to both adherend surfaces and dried. The resulting dry, non-tacky surface will adhere to nothing but itself. When ready to assemble the joint, the two adherend surfaces are accurately aligned and brought together, the bond forming on contact. Heat and pressure are recommended for attaining optimum strength.

3. Film-type adhesive, both supported and unsupported—These films provide a glue line of predetermined and controlled dimension which can be applied by unskilled workers with no special equipment. Three types are currently available: 1) pressure sensitive film, 2) elastomer-phenolic film, both supported and unsupported, which is heat or solvent activated, and 3) epoxy film with a glass cloth reinforcement.

Other types of adhesives that may be used for bonding plastics include those based on 1) synthetic rubbers or thermoplastic resins combined with thermo-

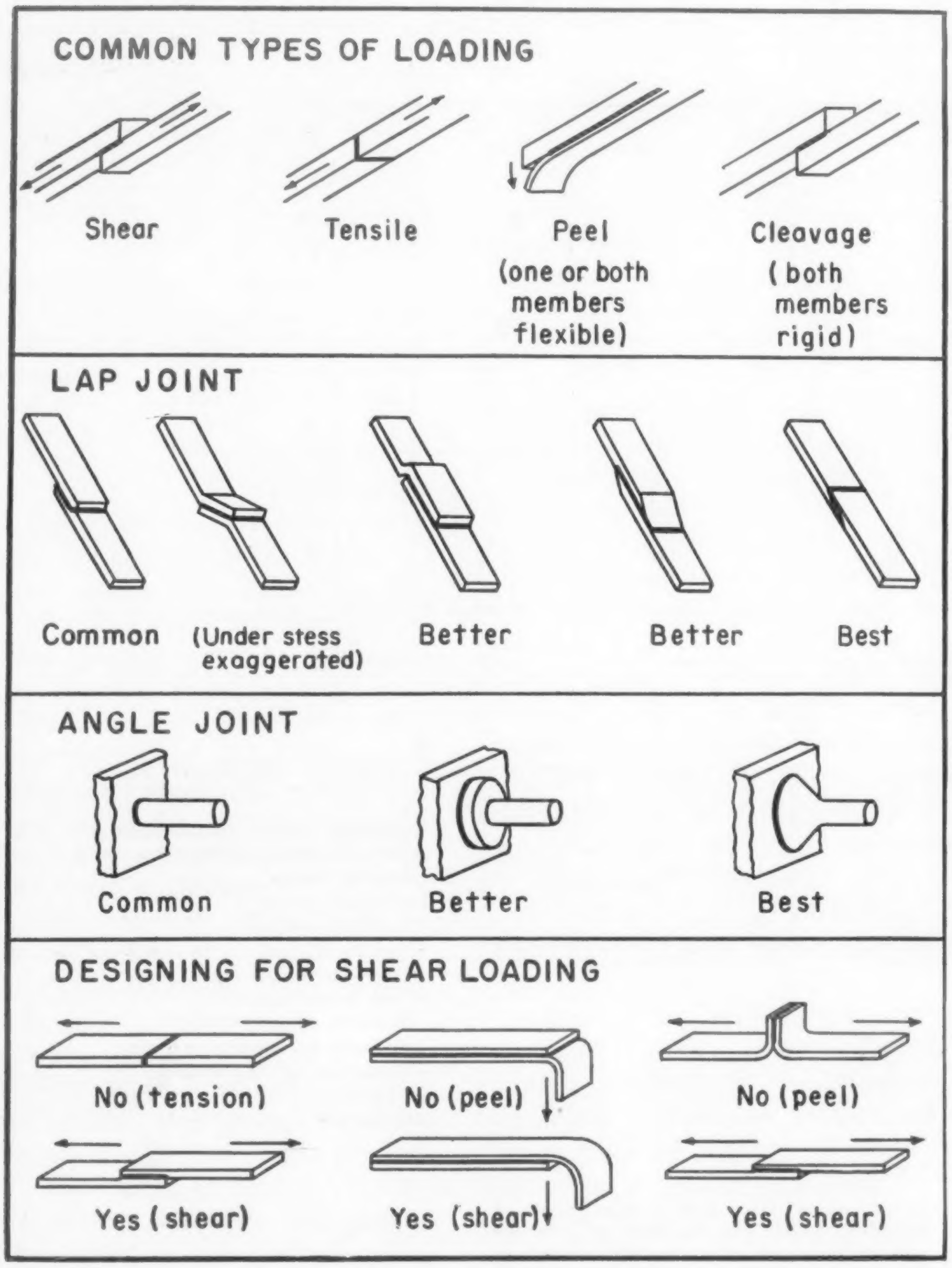
How to design maximum

Each adhesive has greater strength in one direction than in another. The primary purpose in effective adhesive designs is to load the adhesive bond in the direction in which it is strongest. The first drawing opposite shows the various directions of loading common to adhesive joints.

In general, good design avoids types of loads and joints which concentrate stresses in a small area or on an edge. Joints which put the adhesive in shear are usually preferable because adhesives are generally strong in shear.

Thermosetting adhesives and a few adhesives which are neither thermoplastic nor thermosetting are relatively rigid and exhibit high tensile and shear strengths, under both dynamic and static loading. They also have good fatigue characteristics. Rigid adhesives have relatively poor strength when stressed in peel or cleavage.

Some thermoplastic adhesives show high tensile and shear strength but have poor resistance to constant or vibrating stresses. Rubber-based thermoplastic adhesives have low tensile or shear strength but develop high peel or cleavage strength because of film elas-



setting resin, 2) natural, synthetic or reclaimed rubber, 3) thermosetting resins, 4) thermoplastic resins, and 5) miscellaneous base materials, such as resorcinol formaldehyde, casein, oleoresin, and animal glue. The accompanying adhesive reference chart, Table 5, indicates the chemical types of adhesives generally satisfactory for bonding various types of plastics.

Selection factors

In selecting an adhesive for a critical plastics bond a great deal of time and trouble can be saved by consulting the adhesive formulator and supplier. The more the adhesive supplier knows about the specific requirements of a particular adhesion problem, the more effectively and economically the problem can be solved. Following are the major factors which should be discussed with the adhesive supplier.

Materials to be bonded—Not only the chemical nature of the plastics to be joined but also their form (e.g., film, sheet, moldings or foam) is usually critical in selecting an adhesive.

There are available today adhesives chemically suitable for bonding any type of plastics material. The inertness and antistick surface characteristics of fluorocarbon resins have caused considerable difficulty in adhesive bonding such materials. In the last few years, however, there has been developed a method of chemically etching the bonding surface to provide "tooth" for the adhesive, permitting relatively strong mechanical bonds to be obtained.

The form of the plastic in many cases may determine the type of adhesive to be used. For example, the form of the material may require a certain degree of elasticity or resilience in the bond. Assessing the effects of these factors on

strength adhesive bonds

ticity. Under impact loading, regardless of direction of stress, the adhesive must be elastic or resilient.

There are four relatively simple recommendations for obtaining maximum strength in an adhesive bond. These are:

1. Make the bonded area as large as possible.
2. Make the maximum proportion of the bonded area contribute to the strength.
3. Stress the adhesive in the direction of its maximum strength.
4. Minimize stress in the adhesive's weakest direction.

The drawings show several examples where these four recommendations are used to improve joint design.

Lap joint

Common—Such a joint deforms under high stress in such a way as to provide peel stresses at the edges of the bond.

Better—Joggle and beveled lap joints provide higher strength because the maximum proportion of bonded area contributes to strength, and because stress is minimized in the adhesive's weakest direction (i.e., peel).

Best—In addition to the two benefits gained in the "better" designs, the adhesive is now stressed in the direction of its maximum strength (i.e., shear).

Angle joint

Common—If the stress is directly on the pin and at right angles to the flat surface, stress distribution will yield high strength. If the load is not exactly at a right angle to the plane of the joint the result will be concentration of stress in cleavage.

Better—In this design the bond area has been made as large as possible, and the maximum proportion of the bonded area now contributes to strength.

Best—This joint has the advantages of the "better" joint plus the additional advantage that stress is now minimized in the direction in which the adhesive is weakest (i.e., cleavage).

Designing for shear loading

The drawings show bad and good designs for each of three different combinations of materials. In each case the good design puts the bond in the most advantageous stress condition for high strength (i.e., shear).

the selection of the adhesive is best left to consultation with the adhesive supplier.

Service conditions—Next to the materials to be bonded, the service conditions under which the bond must operate are probably the most limiting factors in adhesive selection. The following factors must usually be considered:

1. Temperature limits. Adhesives are available that will provide continuous-load bearing bonds at temperatures as high as about 500 F and as low as -67 F. When evaluating the need for temperature resistance, consider the temperature at the glue line. Though other parts of an assembly may reach higher or lower temperatures, the maximum or minimum temperature to which the actual glue line will be exposed defines the requirements of the adhesive.

Adhesives are broadly broken down into thermoplastic and thermosetting materials, though some combinations cannot be correctly classified as either. If constant service temperatures in excess of about 225 to 250 F are to be encountered, a thermosetting adhesive is almost always required, since most thermoplastic adhesives soften at temperatures in this range. From room temperature to about 250 F a thermoplastic adhesive may be satisfactory, depending on the load.

The thermal characteristics of the plastics to be bonded have an important effect on selection of an adhesive for a bond that will be subjected to heat or cold. Materials with dissimilar coefficients of thermal expansion expand and contract at different rates, requiring a degree of flexibility in the bond. Also, it is unnecessary and usually uneconomical to select an adhesive with a service temperature range broader than that of the materials being joined.

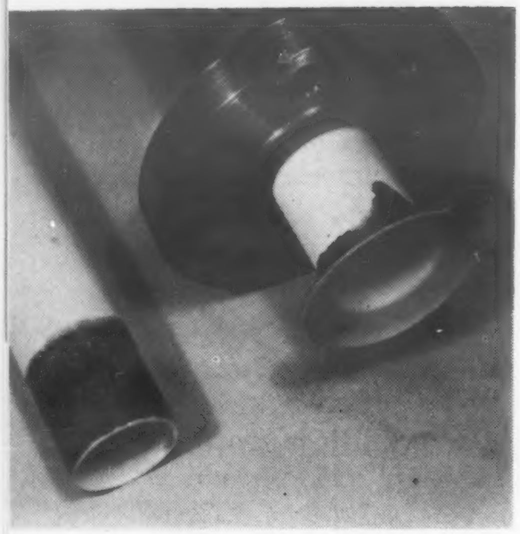
In considering the effects of temperature on adhesive selection, other service conditions, such as chemical exposure and mechanical loading, cannot be ignored. Effects of fluids such as water, solvents and oils are accelerated at elevated temperatures. On the other hand, designing a joint so that the ideal stress conditions are present makes it possible to obtain the maximum useful temperature range from any adhesive.

2. Load and stress requirements. Strength requirements for a particular bond should be considered not only in terms of the adhesive bond but also in terms of the plastics adherends. In general, costs of adhesives increase as bond strengths increase. Thus, for economical bonding, strength requirements should not be exaggerated. In many cases, service tests to destruction should be carried out to determine accurately the actual strength requirements.

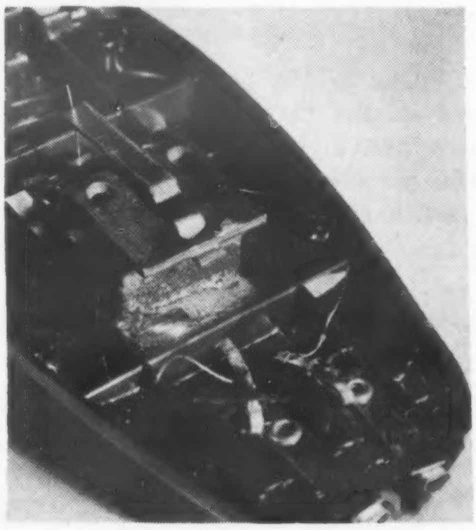
A condition of constant stress should be investigated in any joint design. An example of such a condition is the bond adhering a sheet material to a convex surface. Such a joint in most cases is under a "dead load stress," since the bent sheet tends to return to its flat configuration. The deterioration caused by this constant stress may cause the bond to fail at loads substantially lower than those required to produce a failure in short time strength tests.

Stresses in an adhesive bond may be in shear, tension, peel or cleavage, depending on the design of the assembly (see box on p 136). Adhesives differ in their bond strengths in each of these directions. If the stress condition of the design is known, an adhe-

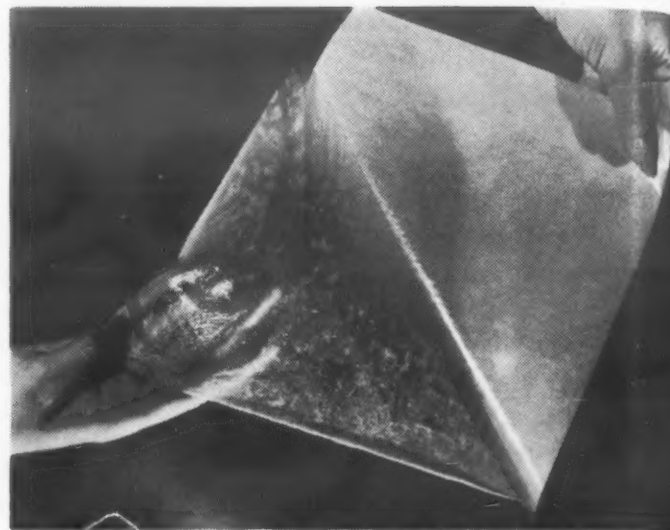
Some recent developments in adhesives



Epoxy *100% solids adhesive bonds cementable tetrafluoroethylene lining to steel pipe.*



Contact *adhesive (solvated neoprene) bonds Alnico magnet to polystyrene housing.*



Photos Rubber and Asbestos Corp.

Film-type *adhesives, such as this pressure sensitive one, are now available.*

sive can be selected with maximum strength in the direction in which the bond will be loaded.

3. Resistance to environments. Anticipated service environments, such as exposure to moisture, chemicals and weathering, should be carefully considered to determine their effects on the adhesive bond.

The degree of fluid resistance required depends both on the assembly and on external conditions. Usually an adhesive is exposed only as a thin line at the edge of an assembly. Thus even direct contact with solvents or other liquids is not always detrimental provided the liquids are not absorbed into the assembled part.

In general, thermosetting adhesives have the greatest resistance to oil, water, acids, alkalis and solvents. Among all adhesives there is a wide variation of resistance to these liquids. In general, where resistance to liquids is critical, adhesives can be supplied with chemical stability at least similar to that of any of the plastics materials (with the exception of the fluorocarbons).

Adhesives to be used outdoors should have resistance to water, heat, cold and, depending on the locale, air-borne corrosive materials. The combined action of any or all of these factors will age some adhesives rapidly; upon other adhesives these factors may have little or no effect.

4. Other factors. Several other service requirements may be important in selecting the proper adhesive for joining plastics.

For example, many types of adhesives can be supplied in a wide variety of colors for applications such as bonding transparent plastics films to other materials to provide a decorative effect.

Any other requirements, such as minimum odor, low toxicity or absence of staining, should be explained in detail to the adhesive formulator or supplier.

Method of application — Adhesives are available as solvent or water-base liquids, mastics or pastes, dry films, or powders. The method of applying the adhesive is as important as selecting the proper adhesive, since improper application is as often the cause of unsatisfactory performance as is poor choice.

Also, in many cases extensive economies can be realized by obtaining a particular chemical type of adhesive in a form that permits use of facilities already present in the fabricator's plant. Since most adhesives for joining plastics can be formulated for application by virtually any method, knowledge of the method preferred by the designer or engineer (based on existing plant facilities) can permit the adhesive supplier to formulate the adhesive accordingly. A straight-line manufacturing process with parts handled by mechanical conveyor obviously is the most desirable technique where quantity production is involved.

The most common application methods are summarized below:

1. Spray coating. Spray and roller coating are the two methods most adaptable to straight-line production techniques.

2. Roller coating. This method is fast and economical where continuous production of sheets of one thickness is involved.

3. Extrusion. In certain applications adhesives may be applied most efficiently by means of an extrusion gun. Extrusion gun techniques are best suited to jobs where a bead or ribbon of adhesive must be accurately placed.

4. Trowel or knife coating. Heavy-bodied adhesives can often be applied most effectively by trowel or knife coating.

5. Brush coating. This tech-

nique is used for small or irregular parts, or for applications where volume does not warrant investment in more elaborate equipment.

Assembly and cure—The methods of assembling and curing the adhesive in many cases affect both the method of applying the adhesive and the selection of the adhesive in the first place. Assembly requirements include time, heat and pressure. They vary with both the adhesive used and the materials bonded.

Two time factors are involved: 1) open time, or the period of time that can or must elapse between coating the parts and joining them (some adhesives permit no open time at all; others must be kept open for intervals ranging from 5 min to 24 hr), and 2) setting time, which is the period that must elapse before full strength is attained. This time may range from seconds to weeks, depending on the adhesive, the materials bonded and the curing procedure.

Heat cures are advantageous in that they speed drying, make drying independent of weather conditions, and prevent water condensation on the adhesive film. The degree of heat used to cure thermosetting adhesives can be critical in selecting the proper adhesive, particularly where end-service temperatures must be considered.

In general, non-load-bearing parts can be designed for a room temperature cure and still operate at temperatures up to 500 to 600 F. Load-bearing parts to be exposed to temperatures ranging only from room temperature to about 180 F can also be designed for a room temperature cure, though use of heat will speed the cure. Load-bearing parts to be exposed to temperatures over 180 F generally require a heat cure. Briefly, if heat resistance is a critical design requirement, heat should generally be used to cure the adhesive. Usually the higher the anticipated service temperature, the higher should be the temperature of cure.

Thermal Welded Joints

Essentially all thermoplastic resins can be joined by thermal welding techniques. Polyethylene and PVC are particularly adaptable to welding and are the most common plastics joined by hot gas welding. Nitrocellulose plastics cannot be welded because of their instability at elevated temperatures.

The suitability of a plastic to thermal welding depends primarily on the melting temperature range. A range, rather than a sharp melting point, is desirable to provide good control over the process.

All thermal welding techniques employ heat to soften the bonding areas to fusion temperature. After joining, the weld is cooled, hardening the materials and forming the joint. The major differences among the various methods of welding plastics lie in the method of applying heat to the material. The four principal welding methods are: 1) hot gas, 2) heated tool, 3) induction heating, and 4) friction.

Hot gas welding

Hot gas welding is used primarily for joining polyethylene and PVC. High density polyethylene, polyvinylidene chloride (Saran), acrylics and chlorotrifluoroethylene have also been welded successfully.

The process uses burning gases from a welding gun to heat the material to the fusion point. Usually a welding rod of the same composition as the parent plastic is used to provide filler material. Electrically heated welding guns are also available.

Proper joint preparation is essential to sound welds. In butt welding, the ends to be joined should be beveled to include an angle of 60 deg. In lap and fillet welding, the surfaces should be solvent cleaned or mechanically roughened. Any lubricants or mold release agents should be completely removed.

Orifice temperatures in welding vary from 400 to 600 F. The distance between gun tip and weld bed usually varies between 1 and 2 in., and in this distance a temperature drop of about 200 F is encountered. Common linear welding speeds range from 5 to 8 ipm, the speed being dependent on type of weld and skill of the operator.

Strength of welds—In hot gas welding of plastics complete fusion does not take place as it does in metal welding. Thus, welds are seldom as strong as the parent plastics. Best welds are obtainable with low density polyethylene which provides weld strengths of 95 to 100% of the ultimate tensile strength of the parent material. High density polyethylene provides lower weld strengths—in the neighborhood of 50 to 60%. PVC welds have weld strengths in the range of 75 to 90%.

Weld strength of crystalline resins such as polyethylene varies considerably with the molecular structure of the base polymer, usually increasing with increasing molecular weight and with decreasing crystallinity. The weld strength of a crystalline resin is also a function of time and usually increases logarithmically from the time the weld is completed, due to the reorientation of the molecular structure as it approaches crystalline equilibrium. With low density polyethylene welds, maximum strength is attained after 4 hr.

Heated tool welding

Heated tool welding of sheet and moldings and heat sealing of film are essentially the same. Both techniques make use of a heated tool to bring the plastic to fusion temperature. The major difference between the techniques is primarily due to the difference in the thickness of the materials. In heated tool welding of sheet and moldings the source of heat is applied directly to the surfaces to be joined; when the materials reach fusion temperature the surfaces are joined with sufficient pressure to cause effective fusion, and then are allowed to cool. In

heat sealing of film, the material is lapped as desired and heat is applied through the film, thus fusing the lapped material.

Heated tool welding has been used primarily with vinylidine chloride polymers and with acrylic sheet, but is applicable to other thermoplastics as well.

Common techniques—A variety of tools can be used in this type of welding:

1. In butt welding sheets, an electrically heated blade is positioned accurately so that the two edges of the sheet are in contact with the blade. Accurate jigs and clamps are required to hold the sheets in alignment and provide sufficient bonding pressure, yet prevent buckling or flexing of the sheets. When the edges of the sheets have reached fusion temperature, the blade is raised and the sheets pressed together and allowed to cool, forming the weld.

2. For simple welds, the parts to be joined can be held against a nickel plated hot plate until they reach fusion temperature, at which time they are joined.

3. For lap welding sheets in such applications as tank linings, a soldering iron fitted with a copper shoe is particularly useful. The heated shoe is passed along between the two lapped surfaces at such a rate as to bring all areas of the bonding surfaces to fusion temperature. As the shoe is moved along, the softened areas are allowed to join and are pressed together with a hand roller to effect fusion.

Special techniques—The fluorocarbon plastics, though technically thermoplastics, require special techniques to provide effective thermal bonds. Both TFE (tetrafluoroethylene) and CFE (chlorotrifluoroethylene) have extremely good heat resistance; thus higher temperatures are required to weld them.

The bonding operation is not as critical with CFE as it is with TFE. CFE requires temperatures of 420 to 440 F and pressures of 25 to 75 psi to provide effective thermal bonds. Care must be taken to obtain uniform temperatures over the entire area of the surfaces to be joined.

TFE can be welded with contact heaters at temperatures of about 700 F and pressures of about 35 psi. Sections 1/16 in. thick provide optimum results, since they have the strength necessary for fabrication, yet are thin enough to be brought to temperature in a relatively short time. Thicker sections require more time for heat transfer. Sheet stock after welding should be stress relieved for 2 hr at 90°F above the maximum anticipated service temperature (for additional information see MATERIALS & METHODS, June '57, p 143).

Heat sealing

Heat sealing of film has become a widely used technique in packaging applications. Many types of automatic equipment have been developed for heat sealing film in production volume. Table 6 lists the heat sealing temperature ranges applicable to the various plastics films.

Nitrocellulose film is not heat sealable because of its sensitivity to heat; and TFE film is not heat sealable because of its heat resistance. Cellophane and polyester (Mylar type) films are inherently non-heat sealable; however, both types are available coated with heat sealable polymers. A new type of polyester film is now available that can be heat sealed (see MATERIALS IN DESIGN ENGINEERING, Sept '57, p 104).

Thermoplastic film can also be heat sealed to thermoplastics in other forms. For instance, a great deal of interest is currently centered on heat sealing of film to vinyl foams.

Equipment for heat sealing is of two general types: that containing electrical resistance elements which heat jaws, rollers or metal bands; and high frequency generators, which make use of the electrical resistivity of the plastic

Two applications of hot gas welding

Photos American Agile Corp.

***Polyvinyl chloride** can be joined by hot gas welding to provide fusion bonds of relatively good strength.*

***Polyethylene** extraction column constructed by hot gas welding.*

TABLE 6—HEAT SEALING TEMPERATURE RANGE FOR PLASTICS FILMS (F)

Cellophane (coated)	200–350
Cellulose Acetate	400–500
CFE (chlorotrifluoroethylene)	415–450
Polyester (coated)	490
Polyethylene	250–375
Polystyrene (oriented)	220–300
Polyvinyl Alcohol	300–400
Polyvinyl Chloride and Copolymers (nonrigid)	200–400
Polyvinyl Chloride and Copolymers (rigid)	260–400
Polyvinyl Chloride-Nitrile Rubber Blend	220–350
Polyvinylidine Chloride	285
Rubber Hydrochloride	225–350
TFE (tetrafluoroethylene)	Will not seal

itself to develop heat within the film.

Induction welding

Induction welding is exceptionally fast and versatile. The heat source is that generated by a high frequency electrodynamic field and induced in a metallic insert placed in the interface of the areas to be joined. The heat from the insert brings the surrounding plastic to fusion temperature. One of the major limitations of the process is that a metallic insert of one kind or another must be integral in the final weld.

Induction welding is one of the fastest methods of joining plastics. Some applications require as little as 1 sec of weld time. Typical applications require from 3 to 10 sec. Production speed is generally limited only by the speed with which parts may be assembled and removed from the welding jig.

Techniques and design—Successful welds can be obtained using stamped foil inserts, standard metallic shapes such as wire screens, or various other configurations of conductive metal. The shape of the insert is not limited to the normal closed resistance circuit pattern; it may be a shape that provides a decorative effect in the finished part, e.g., stars or letters. When using wire, diameters ranging from 0.010 to 0.030 in. are usually most effective. Printed or metallized inserts may be feasible, but they have not as yet been fully evaluated.

The higher the applied pressure on the joint during welding, the higher the permissible temperature. Maximum applied pressure appears to be limited only by the strength and stiffness of the parent materials. In most applications a minimum of 100 lb per linear in. of metal insert is required. The joint should be designed so that pressure is distributed uniformly throughout and over the metal insert.

Though the insert should be located as closely as possible to the generator coil, if it is not centered accurately within the coil it may be attracted by the coil and become misaligned. A tongue and groove joint or a similar configuration is desirable to locate and hold the metal insert. In any case, the insert must be located in the interface so that no portion of it is exposed to air; such exposure could cause rapid heating and subsequent disintegration of the insert.

Strength of welds—Strengths of induction welds are limited by the relatively small area over which the actual weld is formed. Welding occurs only in the area immediately adjacent to the metallic insert. In most cases this area covers 1/16 to 1/8 in. along the periphery of the insert. Very little if any strength is obtained by metal-to-plastic bonding along the surface of the insert.

Weld strengths can be calculated by multiplying weld material strength by the area over which melt is formed. With a wire screen insert between polyethylene slabs, weld strengths better than 50% of that of the parent material can be consistently produced. Acrylics have been processed equally well, and from all indications welds of significant strength can be obtained in almost all thermoplastics.

Spin or friction welding

A welding technique that has been the object of quite a bit of commercial interest recently is spin or friction welding. The process utilizes frictional heat generated by rubbing two thermoplastic surfaces together to heat and fuse the two areas. Welds are said to have strengths similar to those of the parent material.

Advantages of spin welding are: 1) it is excellent for welding thermoplastics that may oxidize at high temperatures, since the welding surfaces remain in contact throughout the process, excluding air from the joint, and 2) it is economical since it can be carried out simply and rapidly with standard machine shop equipment, such as drill presses or lathes.

Disadvantages of the process are: 1) configuration of the joint is limited to circular parts (this limitation can in many cases be overcome by designing the required circular weld area as part of a noncircular part), and 2) in some cases flashing may be required to insure complete welds; however, in many such cases joints can be designed in such a manner that excessive flash occurs on internal areas.

The process—Spin welding involves rotating of one of the sections to be welded against the other, which is held stationary. Rubbing contact is maintained at a speed and pressure sufficient to generate frictional heat and melt the adjacent surfaces. When sufficient melt is obtained, pressure is increased to squeeze out all bubbles and to disperse the melt uniformly between the weld faces. Rubbing action is then halted to permit the weld to form. Pressure is maintained until the weld sets up.

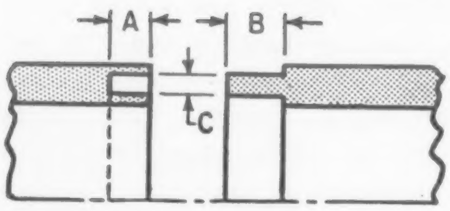
The frictional heat is of such intensity that it produces almost immediate surface melting without substantially affecting the temperature of the material immediately beneath the welding surface.

The heat generated between two rotating rubbing surfaces is a function of the relative surface velocity, of the contact pressure, of the coefficient of friction and of the heat transfer capacity. There seems to be a direct linear relationship between velocity and pressure, i.e., an equal heating effect is obtained by doubling either speed or pressure while holding the other variable constant. This relationship provides for easy conversion from one apparatus to another and, in some cases, from one application to another. Point velocities may range from 5 to 50 fps, initial pressures from 10 to 150 psig.

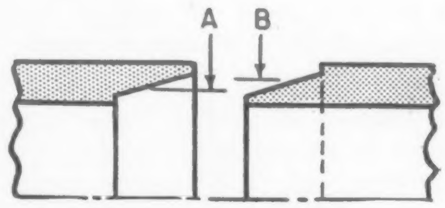
Geometry of the joint is the most important factor influencing weld quality. Joints should provide maximum weld area while minimizing surface velocity differential across the weld area. The box on p 142 gives recommendations that should help in producing practical welds.

How to design for spin welding

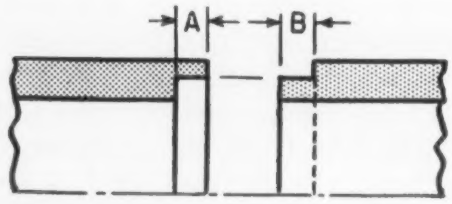
HOLLOW MEMBERS



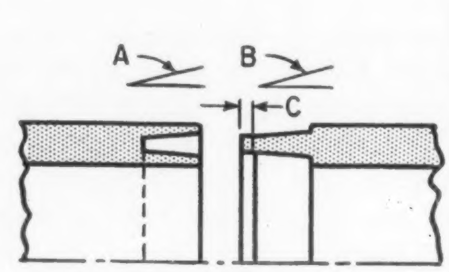
Tongue and groove — *Make tongue B longer than groove A. Width C should be as large as possible, with a slip fit between tongue and groove.*



Matched taper—*Midpoint radius B should be greater than midpoint radius A. The two sections should have different melt points to direct flash.*

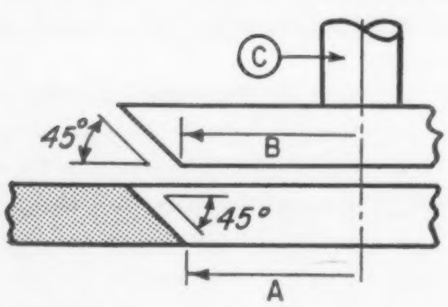


Step—*Should have slip fit between A and B. To direct flash, either A or B should be lengthened and widened.*

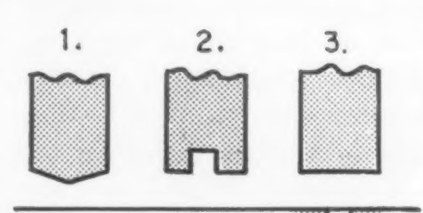


Taper and groove — *Tongue should be as large as possible. Included angle A should be slightly greater than angle B. Small extension such as C should be provided on tongue B.*

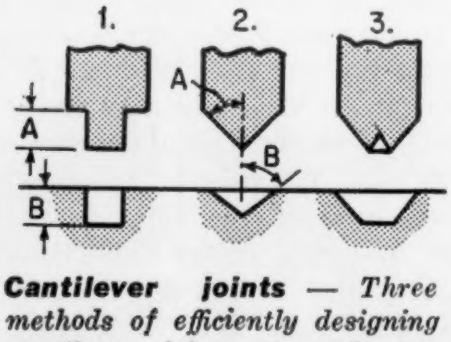
SOLID MEMBERS



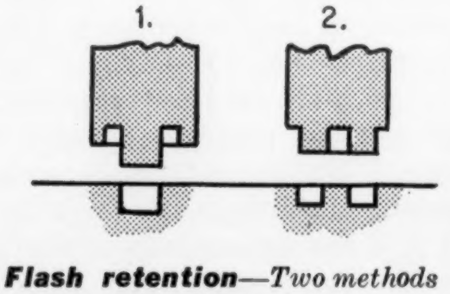
Sheet plug — *Disk radius B should be slightly larger than hole radius A. Driving lug C to be removed after welding.*



Velocity compensation — *Three methods of compensating for velocity differential during spin welding: 1—crowning, 2—removal of center, and 3—using a receiver.*



Cantilever joints — *Three methods of efficiently designing cantilever joints: 1—make extension A longer than receiver B, 2—make angle B greater than angle A, and 3—use combination taper and receiver.*



Flash retention—*Two methods of retaining flash: 1—internal flash retainer ring, and 2—increased joint surface.*

Weld strength—Though no true thermoplastic has been tested that could not be spin welded, weld strengths differ with the material. Thermoplastics with the highest degree of polymerization appear to be the best suited for the technique, since residual monomer is generally unstable at elevated temperatures and tends to gas off; the resulting bubbling action is difficult to control and greatly reduces the strength and clarity of welds. Thus, when spin welding acrylics, molded and extruded materials generally provide better welds than do the cast materials.

Internal stresses are usually produced in spin welded parts, since the heating pattern across the weld area varies due to the differential surface velocity. The stresses are highest at the center of the weld and lowest at the outer surface. Thus internal stresses have little effect on the surface craze resistance or weathering characteristics. However, if the more highly stressed central areas of the weld are exposed to a crazing agent, violent stress crazing results. Annealing of highly stressed joints is desirable.

Internal stresses also affect the tensile and impact properties of the welded part. In some cases they act as points of stress concentration; in others they may actually increase the strength of the part in a given direction. Whenever possible, actual service testing of sample parts should be carried out to determine the suitability of spin welding for specific joining applications.

In addition to welding similar thermoplastics, spin welding can be used to bond thermoplastics to plastics of different melting points and to completely dissimilar materials. When spun against porous materials, such as wood, or against nonporous materials that have been undercut, the thermoplastic melts and flows into the cavities of the mating part. In these cases, of course, the bond is purely mechanical, though strong composites can be produced.

Mechanical Joints

The many methods of providing mechanical fastenings or joints for plastics can be grouped in two broad areas: 1) mechanical fasteners, both of metal and of plastics, and 2) such techniques as swaging, and press and shrink fitting.

Mechanical fasteners

The order of magnitude of the tensile strengths and elongations of plastics materials, as well as their responsiveness to localized stresses, make it apparent that plastics must be treated with more care than metals in designing serviceable mechanically fastened joints. Where joints are to be subjected to loads in service, the stress configuration of the design should be carefully analyzed to determine whether mechanical fasteners are practical.

The relatively recent development of mechanical fasteners made of plastics in a wide variety of types and materials provides the engineer or designer with a wide choice in selecting a fastening device. Fasteners made of plastics are particularly useful for fastening problems involving 1) corrosion resistance, 2) color matching, 3) sealing, 4) protection of painted or porcelained finishes, and 5) electrical insulation. They should not normally be considered where 1) service temperatures are over about 350 F, 2) joints are subjected to high tensile or shear stresses, or 3) piece cost of the fastener is critical.

Though the number of standard and proprietary mechanical fasteners does not permit a complete discussion here, following is a summary of some of the more common methods of joining plastics with mechanical fasteners. For a complete catalog of mechanical fasteners, both standard and proprietary, metallic and plastic, *Fasteners Handbook*, by J. Soled (Reinhold Publishing Corp., 1957), is recommended.

1. Standard machine screws—These are available in both metal and plastic. Holes can be either molded in or drilled after molding. The holes are then tapped and screws inserted. Where the plastic will not provide the thread strength by itself, metal thread inserts can be molded in, or self-tapping metal inserts can be inserted after molding. Metal thread inserts may be of the wire or bushing types. The wire thread type provides particular advantages where the insert is molded in, as the insert contracts during shrinkage of the molding material and does not crack the molding.

2. Self-tapping and drive screws—These types are available only in metal. The unthreaded hole for a self-tapping screw can be either molded in or drilled in the molding, the entering edge being suitably chamfered to prevent spalling. The two basic types of self-tapping screws are those that form threads by displacement and those that form threads by cutting. The former are generally more suitable for use with thermoplastics and the latter with thermosetting materials.

Modified self-cutting screws that distribute stresses evenly are available. These are primarily for use with the more friable thermosetting plastics, such as ureas, or in applications where strains must be minimized, as in the tapping of an island boss.

Whereas self-tapping screws can be removed and replaced with no particular sacrifice in security of the joint, metallic drive-screws are used to provide a permanent assembly. They cannot be replaced once they are removed. Special tools are available for pressing such screws in place.

3. Bolts and nuts—Both metal and plastics bolts and nuts of standard configuration can be used where mechanical requirements of the joined area permit.

4. Rivets—Both metal and plastics rivets can be used to hold parts together securely, or to hold two or more parts together and permit motion between them. Rivets are particularly applicable for use with higher impact plastics materials. To join very thin plastics sections, metallic eyelets may be used instead of commercial rivets. Eyelets are particularly advantageous in providing a bushing for a rivet or metal shaft that must rotate in service. The eyelet minimizes wear of the plastics parts.

Of the rivets used in joining plastics parts, the blind rivet is probably the most common. Blind rivets are available both in metal and plastic and are designed for installation from one side only. Though there are a variety of proprietary designs for such rivets (see *Fasteners Handbook*), essentially they consist of a hollow body and a solid pin. The setting of the rivet is accomplished by driving or pulling (depending on the specific rivet being considered) the solid pin through the hollow shank and thus flaring the shank on the "blind" side of the rivet and providing a positive locking action.

Explosive metal rivets can be used for joining plastics as well as the light metals. Explosive rivets have hollow shanks in which a chemical charge is exploded to expand the hollow shank. Heat is applied to the rivet head with an approved soldering gun. In joining materials of relatively low elastic moduli, such as polyethylene and tetrafluoroethylene, applications are limited to those where low strength joints are permissible, since the expansion of the exploding rivet shank distorts most soft parent materials.

5. Spring clips and nuts—There is a wide variety of proprietary metallic spring clips and nuts that provide inexpensive methods of rapidly fastening plastics parts. These range from simple spring-type fasteners which are forced over a molded stud, to multi-perforated rings, tubular devices and irregular shapes. Such spring devices are often first attached to one of the parts so that rapid assembly can later be completed from one side only.

Fastex Div., Illinois Tool Works

Plastics fasteners, *a variety of which are shown here, can provide strong, sound bonds.*

6. Other devices—A number of means of providing movable assemblies, such as hinges, latches, snap locks and bead-chain attachments, are largely derived from standard or proprietary devices used with common materials of construction other than plastics.

Swaging, press and shrink fitting

Swaging or peening is commonly used to fasten or connect molded parts or metal parts to molded thermoplastic parts. The technique is particularly useful where motion between the parts is required, and is most commonly used to provide an upset head on a molded shaft or pin, or to upset the tips of a V or U slot. Swaging is best accomplished when the part to be swaged is heated to the softening point with a soldering iron.

Press or shrink fitting techniques are universally applicable to similar and dissimilar thermoplastic materials and require no foreign elements such as cement or metal inserts in the finished joints. Properly applied, this technique offers serviceable joints with good strength at a minimum cost.

Plastics are press fitted in the same manner as metals and other materials, but interferences are generally increased to compensate for the relatively low elastic moduli of most plastics. For maximum joint strength, interferences should be made as large as possible without restricting assembly or stressing a part beyond its yield point. Theoretical interference-stress level relationships are based on geometry and materials properties, and specific interferences can be calculated by standard stress analysis procedures.

Where large interferences are not required, shrink fitting may be suitable. Interferences for shrink fitting are determined by adding hub shrinkage to shaft expansion. In some applications it may be practical to shrink fit immediately after molding while the part is still hot, eliminating the necessity for reheating the hub.

Residual joint strengths in press or shrink fitted parts are affected by complex variables, such as apparent modulus and coefficient of friction. For most thermoplastics, variation in apparent modulus becomes negligible after a year, so that joint strength becomes constant. Since the coefficient of friction is affected by variables such as lubrication, moisture, temperature and stress level, the coefficient under each of these conditions must be known in order to accurately calculate the strength of the joint. Axial and torsional strengths of joints can then be calculated by standard equations. When torsional strength is critical, a ribbed shaft should be used; when axial strength is critical, rings or threads should be used. When both torsional and axial strengths are critical, a knurled shaft or combinations of rings and ribs can be used.

When parts are to be press fitted for maximum holding power immediately after molding, they should be freed from internal stresses by annealing. Also, environmental conditions should be carefully considered in designing such joints. Thermal and moisture expansion can be compensated for by designing for the growth expected under the worst conditions (by considering expected expansion as an addition to the interference selected for the desired joint strength). A press fitted plastics assembly experiences its highest stress level immediately after fitting; subsequent environmental dimensional shrinkage is usually more than compensated for by creep.

Internal stresses in a press fitted part may tend to promote crazing in some plastics, such as acrylics and polystyrenes, and may reduce impact strength. Where a pressed part is expected to withstand impact it should be tested under actual conditions to determine the feasibility of this type of joint.

Acknowledgments

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Groov-Pin Corp.
Heli-Coil Corp.
Industrial Fasteners Inst.
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Polymer Corp. of Pa.
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Rubber and Asbestos Corp.

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Cheney, A. J., and Ebeling, W. E., "Methods for Joining Plastic Parts." Paper delivered before 13th Annual Technical Conference, Society of Plastics Engineers, Jan '58.

Thielsch, H., "Adhesive Bonding," MATERIALS & METHODS, Nov '54, p 113.

Plastics Engineering Handbook of the Society of the Plastics Industry, Inc., Reinhold Publishing Corp., New York, 1954.

FILE FACTS

Illium—Materials Data Sheet

Type ➡	G	R
COMPOSITION, %	Ni 56, Cr 22.5, Mo 6.4, Fe 6.5, Cu 6.5, Mn 1.25, Si 0.65, C 0.2	Ni 64, Cr 22, Mo 5.0 Fe 6.0, Cu 2.5, Mn 0.3, Si 0.15, C 0.05
PHYSICAL PROPERTIES		
Density, lb/cu in.	0.31	0.31
Melting Temp Range, F	2440-2290	2500-2415
Ther Cond (212 F), Btu/hr/sq ft/°F/ft	7.0	7.5
Coef of Exp (32-1470 F), per °F	8.5×10^{-6}	8.5×10^{-6}
Specific Heat, Btu/lb/°F	0.105	0.110
Electrical Resistivity (68 F), microhm-cm	124	120
MECHANICAL PROPERTIES		
Modulus of Elasticity in Tension, psi	24.3×10^6	31.1×10^6
Tensile Strength, 1000 psi		
Annealed	—	113
Cold Worked (20% red.)	—	142
As Cast	68	—
Yield Strength (0.2% offset), 1000 psi		
Annealed	—	50.2
Cold Worked (20% red.)	—	128
As Cast	38.9	—
Elongation in 2 in., %		
Annealed	—	54
Cold Worked (20% red.)	—	23
As Cast	7.5	—
Reduction of Area, %		
Annealed	—	71
Cold Worked (20% red.)	—	66
As Cast	11	—
Hardness, Brinell		
Annealed	—	162-178
Cold Worked (20% red.)	—	238-304
As Cast	159-177	—
Impact Strength, ft-lb		
Annealed	—	78
As Cast	6	—
Creep Strength, 1000 psi (0.0001%/hr)		
1200 F	15	—
1300 F	12	—
1400 F	8.5	—
1500 F	5.0	—
THERMAL TREATMENT		
Annealing Temperature, F	—	1900 F (4-5 hr, cool slowly)
FABRICATING PROPERTIES		
Shortness Temperature, F	—	Above 1900 F
Max Reduction Between Anneals, %	—	20%
Machinability	Similar to cast stainless steel	
Weldability	Can be welded by the metal-arc, oxyacetylene and atomic hydrogen processes	
CORROSION RESISTANCE	Resists corrosion by sulfuric, hydrofluoric, nitric and phosphoric acids; neutral and alkaline salt solutions; and fresh and sea water	
AVAILABLE FORMS	Castings	Sheet, strip, bar, welded tubing
USES	Acid pump parts, including bearings, housings, shafts and impellers; spray nozzles, valves, fittings, filters, hardware, thermocouple protection tubes	

◀ For more information, circle No. 483

What's new IN MATERIALS

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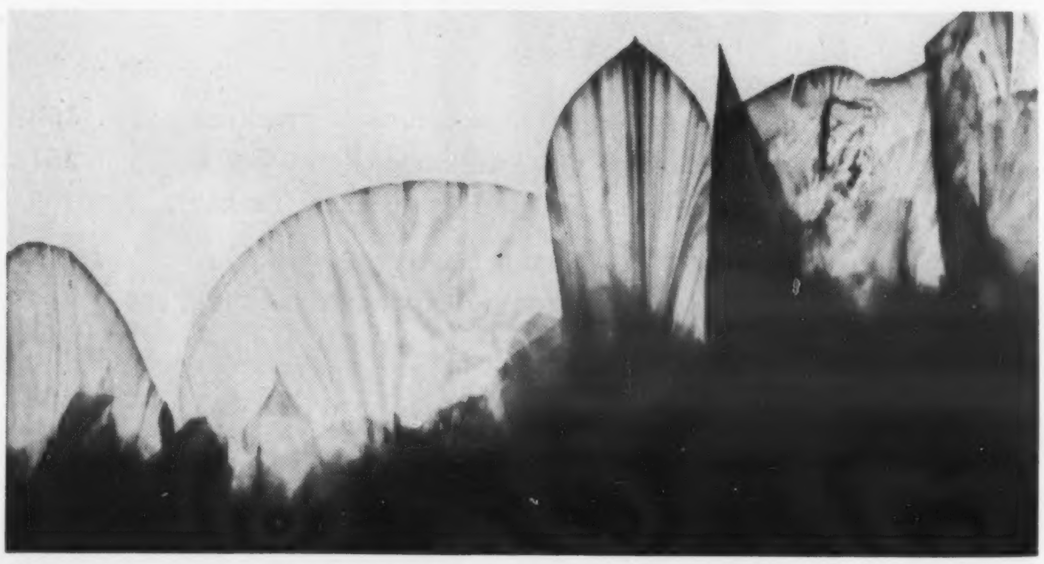
Oxide whiskers *formed on surface of stainless steel subjected to an atmosphere of oxygen and water vapor at 1100 F. (11,200 X)*



Platelets of chromium oxide *formed on prestressed stainless steel subjected to an atmosphere of oxygen and water vapor—with a trace of chloride ions—at 1100 F. (9000 X)*

New Theory Explains Stress-Corrosion Cracking

■ A new theory which may explain the phenomenon of stress-corrosion cracking in metal structures is based on the discovery that minute crystals resembling delicate plates tend to grow from the surface of stainless steels when the metal is stressed and exposed to corroding atmospheres. Specifically, the newly discovered crystals are described as "submicroscopic platelets of chromium oxide," and they form on strongly stressed stainless steel specimens which are exposed to atmospheres containing traces of negatively charged chlorine atoms (i.e., chloride ions).

The discovery, made by Dr. Earl A. Gulbransen, advisory chemist at Westinghouse Research Laboratories in Pittsburgh, is expected to lead to a better understanding of the fundamental mechanisms involved in corrosion. Although it is known that failure of metal structures is often due to a combination of chemical corrosion and internal or applied stress (such as a pull or twist), and that the failure can often be triggered by such relatively mild corrosive substances as steam or human perspiration, little information is available which explains how the phenomenon (known as stress-corrosion cracking) operates.

A possible explanation for this phenomenon, based on the new discovery, is that the growth of platelets on the surface of the steel may lead to "a chemical cutting of the metal." Minute crevices may grow downward into the metal surface as the platelets thrust themselves above it. This may lead to a concentration of stress at the base of the crevices and eventually to failure.

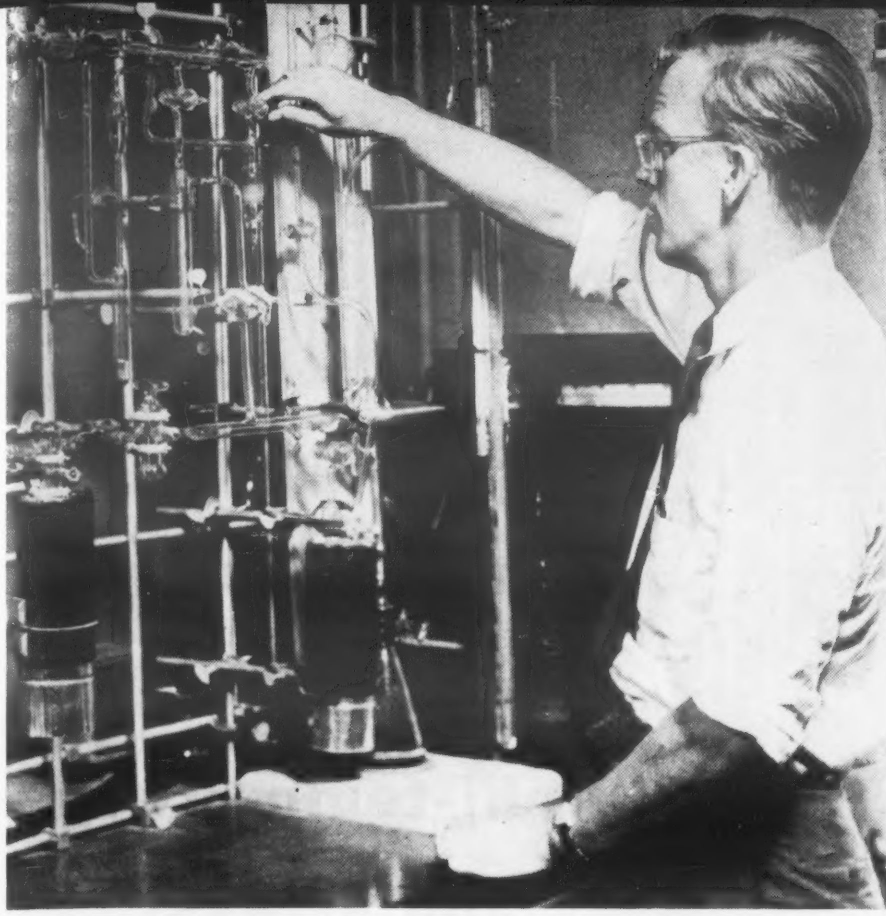
How discovery was made

One of the experiments leading to the new theory involved subjecting a small piece of stainless steel wire 0.009 in. in dia to a carefully controlled atmosphere of oxygen and water vapor at a temperature of 1100 F. A small disk of stainless steel, 0.005 in. thick and having a hole 0.006 in. in dia, was sometimes substituted.

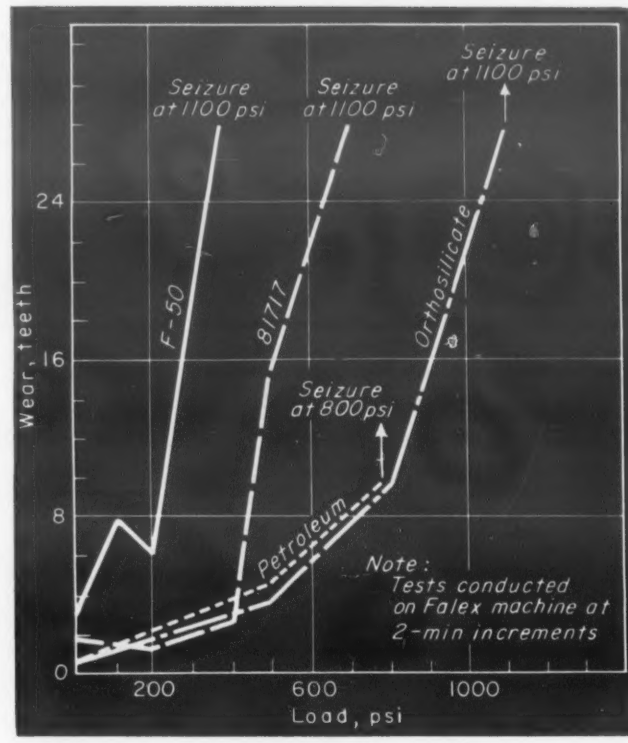
After corrosion by the hot atmosphere, the wire or disk was examined and photographed with an electron microscope. A typical sample was found to erupt with "billions of oxide whiskers." Only about one or two millionths of an inch in thickness, these whiskers grow to a height 300-400 times their diameter. Their density is about six billion per square inch of metal surface.

Completely unexpected changes occur, however, when a sample is prestressed and a trace—less than five parts per million—of chloride ions is added to the atmosphere. Instead of long, thin filaments, rows of thin, upright, parallel plates grow along a definite crystallographic direction. Their thickness is placed at 0.00005 in., or less. Analysis shows them to have the characteristic structure of an oxide of chromium, normally present in stainless steels; in fact each tiny plate appears to be a single crystal of chromium oxide (Cr_2O_3).

Although scientists have known for some time that the chloride ion was a major factor producing stress-corrosion cracking of stainless steels, they did not know how it was done. The knowledge that chloride ions stimulate growth of crystals in strongly stressed metal and that these crystals tend to crack the metal and lead to ultimate failure, may eventually enable researchers to prevent such failures.



Thermal stability of silicone fluids is checked in a newly developed testing device that can be used at temperatures as high as 1000 F.



Load bearing abilities of F-50 and 81717 silicone lubricants are compared with those of petroleum and orthosilicate lubricants.

Improved Silicone Lubricants Operate at 700 F

■ Silicone fluids have remarkable viscosity - temperature stability, and when modified with certain additives have good lubricating properties. The outstanding characteristic of a silicone lubricant seems to be its ability to lubricate for long periods of time at high temperatures—as high as 700 F.

Within recent years a number of companies have been marketing silicone lubricants at a price of around $5 per lb. One company, General Electric Co., Silicone Products Dept., Waterford, N. Y., started marketing these lubricants in 1954 with the introduction of Versilube F-50. Just recently, the company added two more silicone lubricants to its Versilube line: Versilube 81717 and Versilube 81644.

According to GE scientists, the fluids provide greater flexibility in the design of lubrication systems of aircraft, missiles, refrigerators, compressors, clocks and timing devices than previously possible with other lubricants. Versilube 81717, containing a special type of extreme pressure additive, is said to have excellent lubricity over a temperature range of —100 to 600 F, and up to 700 F under special conditions. The other new lubricant, Versilube 81644, contains antioxidant additives and is designed for use in engine and other lubricating systems where exposure to air cannot be controlled. This material is said to remain stable under exposure to oxygen at temperatures as high as 510 F—some 60 to 80 degrees higher than previous silicone lubricants. The third lubricant in the series, Versilube F-50, contains no additives and is said to be useful in all kinds of antifriction and rolling friction equipment at temperatures from —100 to 450 F.

Some potential uses

All three lubricants, said to increase machine productivity, reduce maintenance costs and improve reliability of equipment, should find use in the following items: 1) sleeve bearing motors and other rotating electrical equipment; 2) clocks and timing devices, especially those exposed to wide temperature ranges; 3) instruments and controllers; 4) fluid transmissions; 5) refrigerators; 6) jet aircraft engines and other gas turbines; and 7) hydraulic systems and servomechanisms.

The silicone fluids may be for-

PROPERTIES OF SILICONE LUBRICANTS

Type ➜	F-50	81717	81644
Viscosity, centistokes			
—65 F	—	3487	2848
100 F	37.8	71.3	65.6
210 F	99.0	22.0	22.0
700 F	—	1.9	2.4
Pour Point, F	<—100	<—100	<—100
Flash Point, F	>525	575	560
Fire Point, F	>650	620	620
Specific Gravity	1.03	1.03	1.04

mulated into greases by using conventional soaps, inorganic fillers, metal oxide aerogels, various pigments and inert organic materials. Greases made from these fluids have wide operating temperature ranges and are said to be useful where conventional lubricants fail.

How they perform

Thermal stability—At temperatures much above 600 F silicone fluids begin to break down; however, their breakdown rates are temperature dependent. For instance, at 700 F the breakdown rates for 81717 and 81644 are about 4% per hr or somewhat greater than the rate for Versilube F-50. The breakdown products of the lubricants are noncorrosive, nonabrasive, essentially nontoxic, low molecular weight silicones. The spontaneous ignition temperature of the breakdown products, 900 F, is as high as that of the original fluid. These breakdown products can be removed from the fluids with conventional deaeration equipment, according to GE.

Corrosiveness—All three lubricants are noncorrosive to most metals even at extreme temperatures, according to the producer. A few metals, particularly copper, are attacked at temperatures above 450 F and should not be used in the system. Most materials, such as paints, lacquers, plastics, coated fabrics and specially formulated rubber compounds, are not affected by the lubricants.

Lubricating properties—Generally, the silicone lubricants are capable of withstanding great loads without allowing bearing metals to seize. Since Versilube 81717 and Versilube 81644 contain additives, they have better lubricating properties than Versilube F-50 which contains no additives.

Handling—Since oxidation products of the lubricant are primarily formaldehyde, care should be taken when they are used at temperatures over 450 F.

All three lubricants are now available from GE in drum lot quantities. Versilube F-50 costs $4.95 per lb; Versilube 81717 and 81644 cost about $5.50 per lb.

Water Soluble Plastics Film for Special Packages

■ Plastics packages that dissolve right along with the products they contain, such as soaps, detergents, inks and insecticides, result by using a new family of water soluble plastics that resemble polyethylene. Based on polyethylene oxide, the water soluble resins are formed by linking as many as 100,000 ethylene oxide units into long, linear structures. Said to be truly thermoplastic in nature, the resins range in molecular weight from a hundred thousand to several million. The key properties of cured polyethylene oxide films seem to be good ductility and good plastic memory.

Properties of films

Developed at Union Carbide Chemicals Co., South Charlestown, W. Va. (a division of Union Carbide Corp., 30 East 42nd St., New York 17), the resins, called Polyox, are presently available in limited quantities in four grades.

In addition to being soluble in water, the resins are soluble in acetic acid, chloroform, acetonitrile, methylene chloride, and ethylene dichloride. They can be milled, calendered, extruded and injection molded.

Films made from the resins are said to be characterized by a high degree of crystallinity, good flexibility, toughness and immunity to biological attack. According to Carbide, relative humidities below 90% do not affect the flexibility, surface slip or strength of the films. The films can be sealed at temperatures from 170 to 265 F.

The good ductility and plastic memory of the films are indicated by results of tests in which the film is elongated from 700 to 1000% without breaking and returns to its original size and shape with the application of heat.

Other uses

Because of their relatively high tensile strength (1800-2400 psi)

MECHANICAL PROPERTIES OF POLYOX FILM

Tensile Strength, psi	1800-2400
Yield Strength, psi	1300-1500
Ultimate Elongation, %	1100-2000
Tensile Modulus, psi	35,000-40,000
Durometer Hardness	A 99

Tossed into water, *Polyox plastics package, containing a chemical that produces a harmless gas on contact with water, dissolves in 4 sec.*

and inherent tackiness when in solution, the resins should have potential value in binding ceramic and glass compositions; powdered metals; glass, paper and other fibers in specialty nonwoven fabrics; pigments; and welding rod coatings. They should also find use as adhesives and mold release agents. According to the company, preliminary 90-day feeding tests indicate that Polyox resins have low toxicity.

According to Carbide, a development price of \$1.50 per lb has been set for the resins, with the price expected to drop to 35 to 50¢ per lb once they get into full scale production. The company says substantial commercial scale production is scheduled for early 1958, and plans are now being formulated for a large scale unit to be completed in 1960.

Acetal Plastic May Compete with Nylon

■ "Strong, tough and durable in the presence of organic solvents, moderate temperatures (250 F) and high humidities"—that's what Du Pont is saying about its relatively new thermoplastic material, Delrin acetal resin. Some observers call the resin a "poor man's nylon" because its properties are similar to those of nylon and because it is produced from formaldehyde, one of the lowest cost monomers used in plastics.

Announced late in 1956 by the Polychemicals Dept., E. I. du Pont de Nemours & Co., Wilmington 98, Del. (see MATERIALS & METHODS, Feb '57, p 153), the resin is expected to be in commercial production by 1959. It is believed that its cost will probably be around \$1 per lb at initial production and less than 80¢ per lb once production gets going. At present, the resin is available in limited quantities as a general purpose injection molding resin designated 500X, and as a general purpose extrusion resin designated 150X.

Delrin

Delrin acetal resin is a high melting, high crystalline linear polymer derived from formaldehyde. It has a unique chemical structure consisting of alternate links of carbon and oxygen atoms. It is over 50% oxygen by weight.

Many potential uses

Design engineers should find many uses for the resin in appliance, automobile, truck and business machine parts. According to Du Pont, Delrin has proved its toughness in service tests performed on automobile door latch

PROPERTIES OF DELRIN

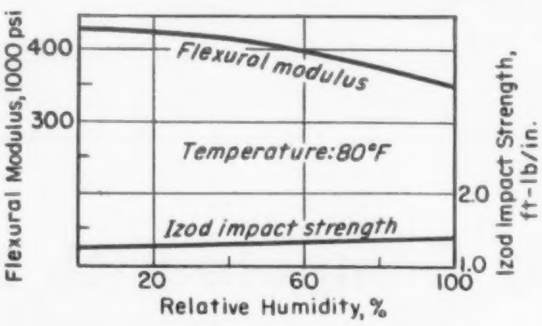
PHYSICAL PROPERTIES	
Thermal Conductivity, Btu/hr/sq ft/°F/in.	1.6
Specific Heat, Btu/lb/°F	0.35
Water Absorption, %	
24-Hr Immersion	0.4
Equilibrium, 50% RH	0.2
Specific Gravity	1.425
Flammability, in./min	1.1
Melting Point (crystalline), F	347
Flow Temperature, F	363
Deformation Under Load (2000 psi, 122 F), %	0.5
Compressive Stress at 1% Deformation, psi	5200
Coef of Ther Exp, per °F	4.5×10^5

MECHANICAL PROPERTIES	
Tensile Strength (and Yield Point), psi	
−68 F	14,700
73 F	10,000
158 F	7500
Elongation, %	
−68 F	13
73 F	15
158 F	330
Izod Impact Strength, ft-lb/in.	
−40 F	1.2
73 F	1.4
Flexural Modulus, psi	
73 F	410,000
170 F	190,000
250 F	90,000
73 F, 100% RH	360,000
Flexural Strength, psi	14,100
Shear Strength, psi	9510
Rockwell Hardness	M94
Heat Distortion Temp, F	
264 Psi	212
66 Psi	338
Taber Abrasion (1000 gm, CS-17 wheel), mg/1000 cycles	20

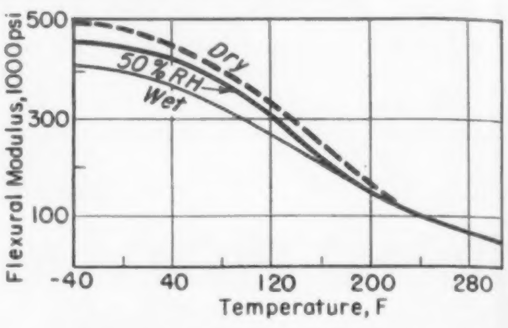
ELECTRICAL PROPERTIES	
Dielectric Strength (short time), v/mil	500
Volume Resistivity, ohm-cm	
0.2% Water	6×10^{14}
0.9% Water	4.6×10^{13}
Arc Resistance, sec	129
Dielectric Constant (73 F)	3.7
Dissipation Factor (73 F)	0.004

***Acetal resin** can be molded into such diverse products as plates, combs, clothespins, knife handles, soap dishes and bottles.*

How heat and moisture affect Delrin



***Effect of moisture** on flexural modulus and impact strength.*



***Effect of heat** on flexural modulus.*

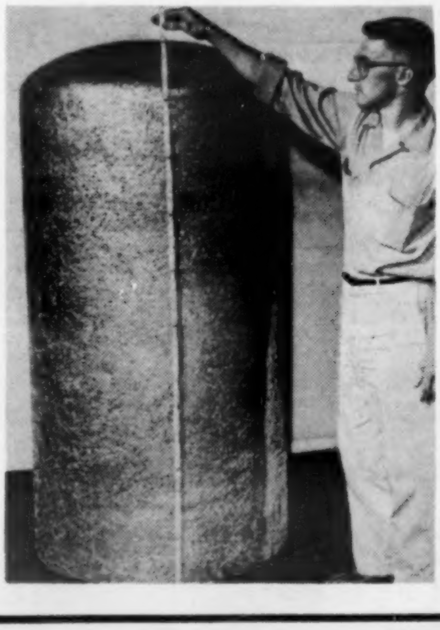
wedges, freezer door rollers, clothespins and many types of gears. Delrin is tough in the sense of "strong and rigid" and should be used where high strength and resistance to bending are required; nylon, by comparison, is tough in the sense of "resilient" and should be used where the ability to yield with a blow is important.

Since the resin has good permeability characteristics in aliphatic, aromatic and halogenated hydrocarbons, and in alcohols and esters, it is very well suited for use in aerosol containers. According to the producer, Delrin is significantly more permeable to water vapor than is polyethylene. A list of some of the material's potential uses follows:

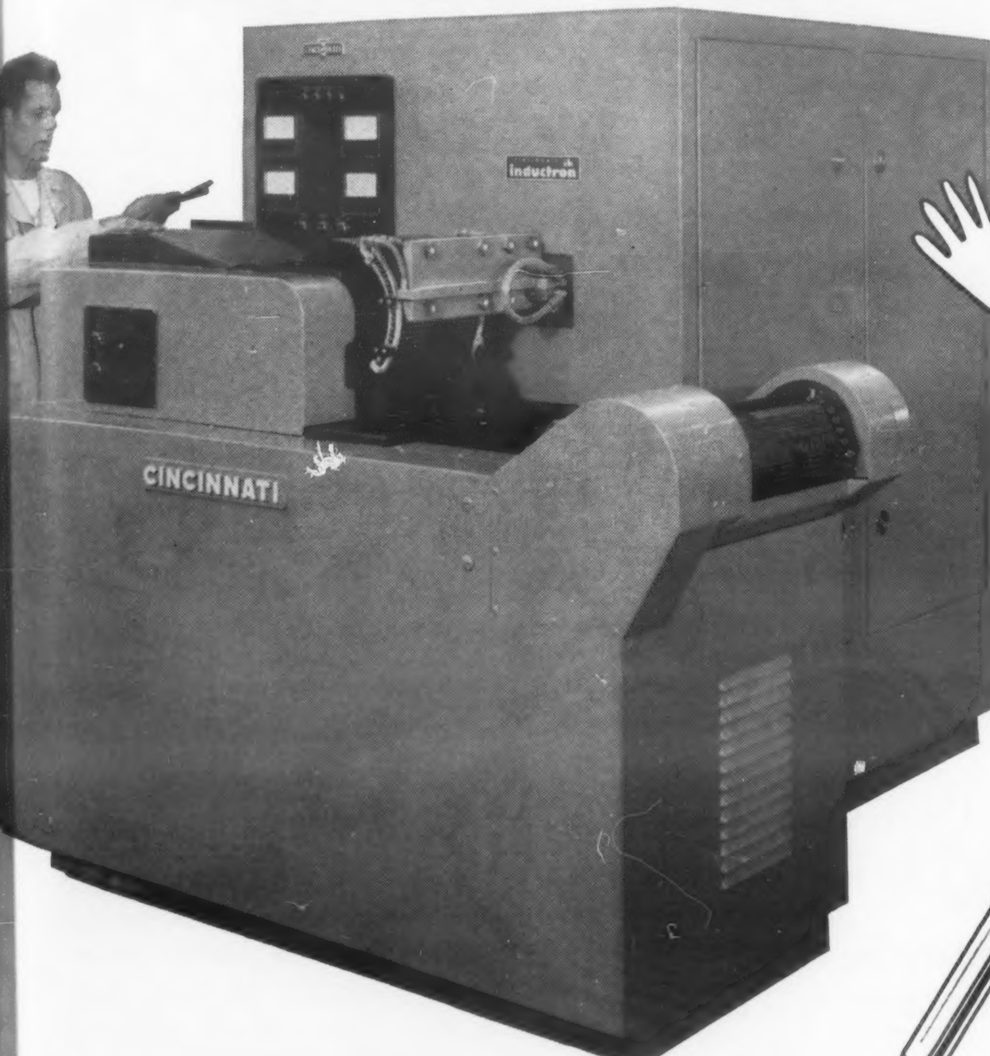
Household uses — Because the resin has good dimensional stability, high tensile strength and flexural modulus, good resilience and toughness, and good recovery from deformation at temperatures from -65 to 250 F, it should find use in many household items, including dinner plates, ice tray dividers, food mixer gears, dishwasher parts, sewing machine gears, shower heads, toothbrush and knife handles and freezer compartment door hinges.

Automotive uses—Du Pont engineers say the resin should find many uses in automobile and truck parts, since it has good resistance

Largest titanium ingot—Pictured here is what is claimed to be the largest titanium ingot ever cast. The ingot, produced by Rem-Cru Titanium, Inc., Midland, Pa., is 32 in. in dia and weighs 7200 lb—the equivalent in volume of a 13,000-lb steel ingot. According to Rem-Cru, requests from the aircraft industry for larger forgings than could be handled by ordinary ingots necessitated the production of the giant ingots. The ingot shown here is in the as-cast condition.



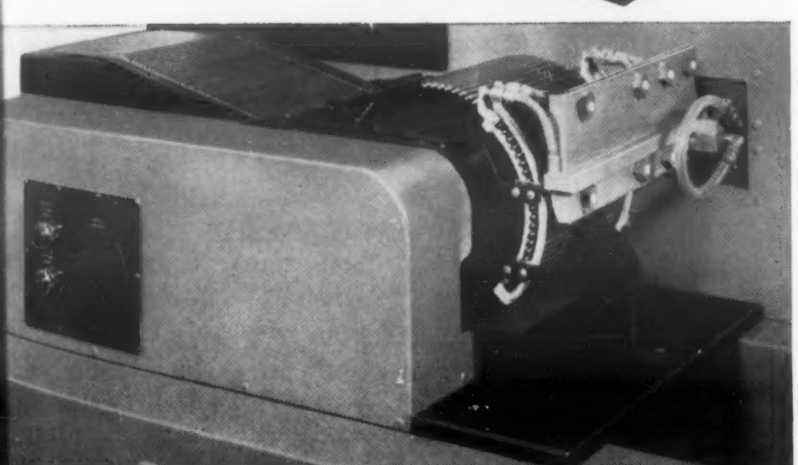
new Cincinnati Inductron hardens push rods at 1-per-second rate!



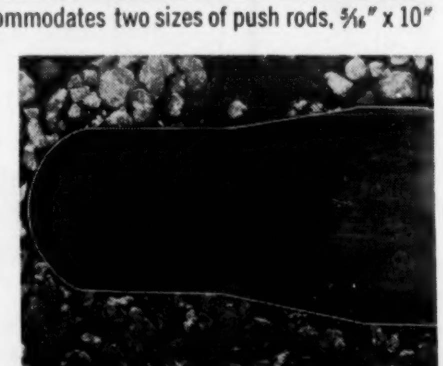
Induction hardening both ends of automotive engine push rods is accomplished at a rate of 3600 parts per hour by this new 15-kw Cincinnati Inductron®, operating at 1.2 megacycle frequency. Except for hand loading the parts into a chute, operation of the unit is automatic. Rods are gravity-fed into a "ferris wheel" which carries the parts through the work coils. Heated parts drop into the oil quench bath at one second intervals. Quenched parts are carried from the tank to tote bins by a conveyor.

This installation is one of many possible Cincinnati Inductron adaptations for the high speed selective hardening of small parts, thin walled and other parts requiring shallow case and narrow transition zone. In addition, the Inductron is equally well suited for low production operations on a wide range of work, using easy-to-form work coils. These high frequency machines are built in water or air cooled 15-kw and 30-kw, and water cooled 50-kw capacities.

You'll profit by taking your selective surface hardening problems to Cincinnati—builders of *both induction and flame hardening machines*. Call in a Process Machinery Division field engineer. He is ideally equipped to evaluate your needs and give you unbiased recommendations as to the most economical equipment for your work.



Close-up view of fixture, which accommodates two sizes of push rods, 5/16" x 10" and 5/16" x 11½". Part material is SAE 1065 steel. Controls include heat and fixture start-stop push-buttons and speed control knob for varying the rate of fixture rotation.



Micrograph showing push rod tip hardness pattern. Hardness achieved is 58-62 Rockwell C, with .050" minimum case depth. Hardened area extends 9/32" back from rod tips.

CINCINNATI

flamatic and inductron

hardening machines

PROCESS MACHINERY DIVISION

THE CINCINNATI MILLING MACHINE CO.

CINCINNATI 9, OHIO, U.S.A.

COEFFICIENT OF FRICTION OF DELRIN ON STEEL

Dry (73 F)	0.1 to 0.3
Dry (250 F)	0.1 to 0.3
Lubricated with water (73 F)	0.2
Lubricated with oil (73 F)	0.1

to impact, solvents, abrasion and cold flow. Typical parts would be electric windshield wiper gears, brake pedal bushings, d.c. generator bearings, door lock wedges, engine timing gears, speedometer take-off gears, gear shift knobs, steering gear bushings, carburetor parts and engine camshaft bearings.

Other uses—Good stain, abrasion, wear, crack and moisture resistance should make the resin useful in coffee cups, fruit juice tumblers, water sprinkler parts, typewriter actuator cams, football shoe cleats, chair caster wheels, lawn mower roller bearings, fountain pens and movie projector gears.

Good mechanical properties

An outstanding feature of this relatively new resin is its good mechanical properties. Du Pont engineers say, "No existing thermoplastic can equal Delrin in its combination of dimensional stability, fatigue life and recovery from deformation over a wide range of conditions. Particularly outstanding are the combinations of strength and toughness at low temperatures and strength and stiffness at high temperatures."

Du Pont engineers and scientists have been studying and evaluating the properties of the resin for the last three years. A summary of their findings:

1. Toughness—Notched Izod impact tests performed on molded Delrin bars show it has an impact strength of 1.4 ft-lb per in. at 73 F and 1.2 ft-lb per in. at –40 F. This retention of toughness with temperature is said to make the resin useful in both hot and cold applications. As temperature decreases from 73 to –65 F, elongation re-

CHEMICAL RESISTANCE OF DELRIN
(Weight Change, %)

Fluid	Exposed at ...	
	Room Temp	122 F
Mineral Oil[a]	+0.3	−0.5[c]
Motor Oil[a]		−0.2[c]
Carbon Tetrachloride[a]	+1.2	+5.7
Ethyl Alcohol (100%)[a]	+2.2	+1.9
Acetone[a]	+4.9	+2.6
Acetic Acid (5%)[a]	+0.8	−2.6
Toluene[a]	+2.6	+2.8
Brake Fluid[a]		+1.6[c]
Ethyl Acetate[a]		+2.9
Sulfuric Acid (30%)[b]	−48.0	
Nitric Acid (10%)[b]	−70.0	
Hydrochloric Acid (10%)[b]	−84.0	
Sodium Hydroxide (10%)[b]	+0.01	1[c]
Sodium Chloride (10%)[b]	+0.05	+0.02[c]

[a] Aged 12 months. [c] Aged at 158 F.
[b] Aged 6 months.

mains essentially the same; however, as temperature increases much above 73 F there is a significant increase in elongation. Delrin is said to be somewhat like steel in bend resistance; i.e., a lot of force is required to bend it, but if it is not bent too far it recovers almost perfectly.

2. Stress resistance—At room temperature and under moderate loads the resin has creep resistance roughly comparable to that of most thermoplastics. When subjected to high loads, prolonged loading and high temperatures, Delrin is said to show a pronounced superiority over other thermoplastics.

3. Fatigue life—Repeated stressing of the cured acetal resin shows it withstands a loading of 5000 psi almost indefinitely, even when immersed in oil, water and solvents. Du Pont engineers say this is a higher fatigue endurance limit than obtained with any other thermoplastic.

4. Dimensional stability — The acetal resin is said to have good dimensional stability for long periods of time at temperatures below 120 F and at high humidities. For instance, hot water was run continuously through a two-part, threaded shower head made

of Delrin resin for 88 days; at the end of the test the thermoplastic threads meshed perfectly, showing that no change in dimensions had taken place.

5. *Abrasion resistance* — The thermoplastic has a coefficient of friction of 0.1 to 0.3 against steel. Also, there is no variation in the coefficient of friction over a temperature range of 73 to 250 F under loads up to 2500 psi. The resin may be used under high loads in unlubricated bearings running at low speeds. Delrin performs about the same as nylon in lubricated bearings.

6. *Weather resistance* — Delrin is affected by ultraviolet light and should be filled with small amounts of carbon black if it is to be used outdoors. Tests have shown that the molded resin does not lose its properties when buried underground, nor is it attacked by fungi, rodents or insects.

7. *Flame resistance*—The resin burns slowly when ignited by a flame, burning at about the same rate as polyethylene, polystyrene, acrylic resins and cellulose acetate butyrate.

8. *Electrical properties*—Dissipation factor and dielectric constant of Delrin are very low at room temperature over a fairly wide range of frequencies. Volume resistivity is high and not markedly affected by water absorption.

9. *Chemical resistance* — The acetal resin has excellent resistance to most organic solvents, including aliphatic and aromatic hydrocarbons. The material is not recommended at the present time for use with strong acids or alkalis.

Conventional fabrication

According to the producer, Delrin, like most thermoplastics, is best suited to fabrication by injection molding and extrusion. The recommended molding temperature for the resin is 380 to 440 F. It may be molded in conventional equipment at somewhat

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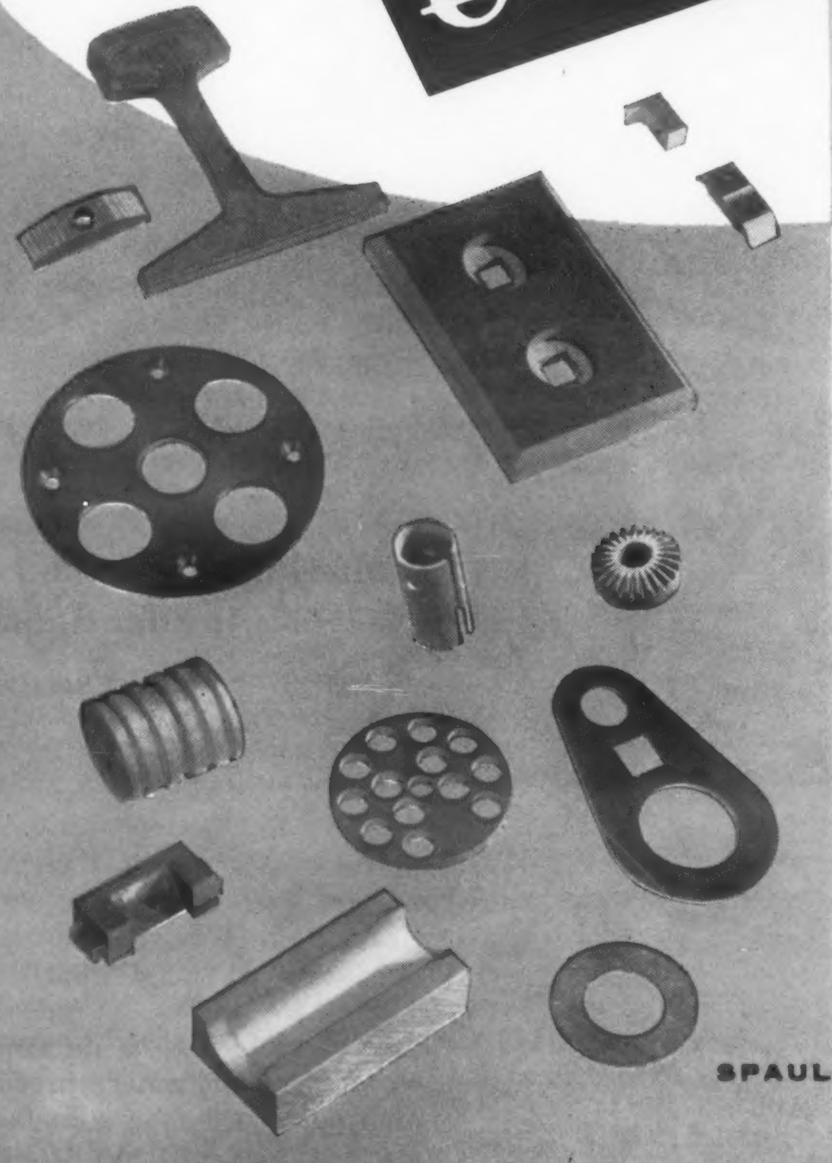

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Known in all industries for its exceptional hardness, density and resilience, Spaulding Supergrey withstands the impact of heavy shock loads. Its extremely smooth wear will not mar contacting surfaces.

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higher pressures than those used for nylon.

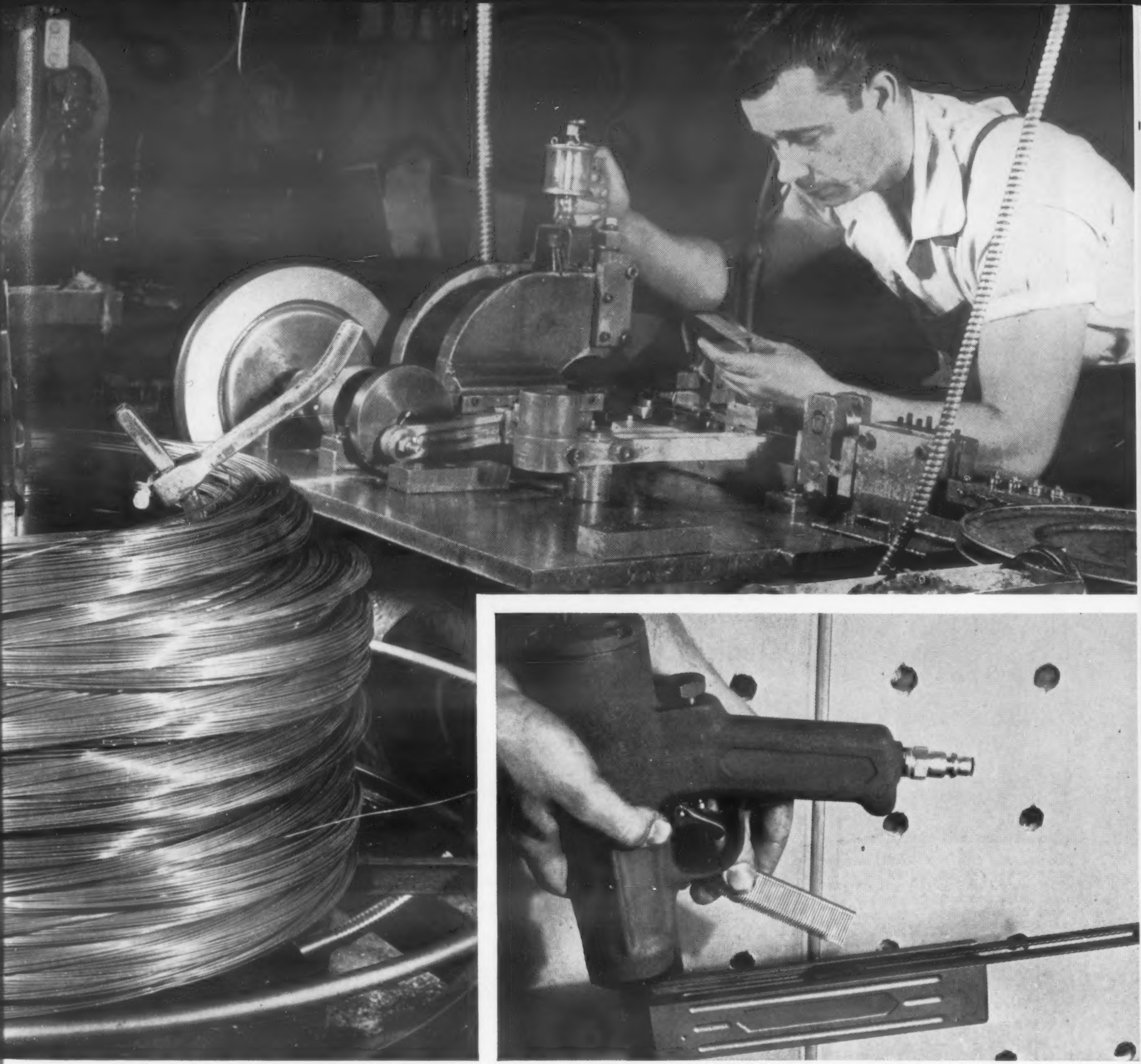
The cured thermoplastic can be sawed, drilled, reamed, threaded, tapped, turned on a lathe, blanked and polished, and it can be joined together by induction, resistance wire, inert gas and spin welding techniques. It is difficult to cement or print the acetal resin. Many standard commercial cements have been tested, and some epoxies, phenolics and rubber-base cements have provided shear strengths as high as 500 psi. In printing, best results have been obtained with the roll leaf stamping method.

Columbium Studied for Hot Applications

High purity columbium metal is being studied for possible use in jet aircraft and missiles by E. I. du Pont de Nemours & Co., Inc., and Thompson Products, Inc., Cleveland. Du Pont is producing the metal in experimental quantities and supplying it to Thompson Products who will develop forging and other fabricating techniques for the metal. (For information on other companies producing high purity columbium metal, see MATERIALS IN DESIGN ENGINEERING, Dec '57, p 182).

Kept reasonably free of nitrogen, hydrogen and oxygen pure columbium metal is extremely ductile and has unusual workability. Du Pont metallurgists report, for instance, that a 1-lb, ¾-in. ingot of columbium can be cold rolled into foil a thousandth of an inch thick without annealing.

The metal oxidizes rapidly at high temperatures, but both strength and oxidation resistance at high temperatures have been materially improved by alloying. It is this high temperature resistance that makes columbium alloys interesting to designers and manufacturers of high speed aircraft



Now you can fasten almost anything with staples shot from guns

Here they're making staples from a coil of Bethlehem 16-ga galvanized steel wire. Not ordinary office-type staples, but big and sturdy industrial staples, ½ in. to 1⅜ in. long, for fastening gypsum and metal lathing. Staples like this can be driven fast with a portable air-gun weighing only about 5 lb.

What a variety of fastening jobs industry is doing with staples these days! They're fastening crates, boxes, bedding, furniture, flooring, siding, roofing, cabinet work. They're even stapling the ribbing on boats!

Producing the right grades of stapling wire, both galvanized and bright, is a familiar task for our modern wire mills. As a matter of fact, Bethlehem turns out steel wire for just about every imaginable use. Some are general purpose grades; others are tailored to meet the requirements of such products as cold-headed screws, upholstery springs, bicycle spokes, lock washers, brush handles, and armor wire for cables.

The steel wire that's best for your product is likely to be a grade and quality we're producing right now. A Bethlehem representative will gladly give you prices, delivery and other details. Just call or write the Bethlehem sales office nearest you. Your inquiry will receive prompt attention.

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For more information, turn to Reader Service card, circle No. 412

What's new IN MATERIALS

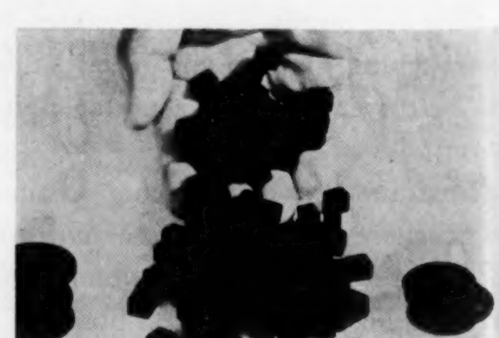
and gas turbine engines. Use of columbium alloys in gas turbine buckets may lead to more efficient turbines capable of running at temperatures in the range of 2000 to 2200 F.

In addition to gas turbines, jet engines and missiles, the metal is being studied for possible use in locomotive, marine and automobile engines, and in stationary power generators. (For more detailed information on columbium, see MATERIALS & METHODS, May '57, p 131.)

Molded Carbon Shapes Adsorb Unwanted Vapor

Molded cubes and wafers of activated carbon are now commercially available from National Carbon Co. (a division of Union Carbide Corp.), 1300 Lakeside Ave., Cleveland 14. Said to be the first such products ever offered, the molded carbon shapes are reported to have high adsorption capacities, and are said to be much easier to handle than activated carbon granules of equal volume. Specially treated to be dust-free, the shapes are formed from powdered, highly adsorbent activated carbon bonded with an organic resin.

The cubical shape (measuring ⅜ in. thick) is recommended as a vapor adsorbent in hermetically sealed relays and precision electronic equipment. Placed in an



***Activated carbon** in the form of cubes and wafers is used for odor and vapor adsorption.*

electronic instrument case before sealing, the activated carbon cube is said to adsorb vapors driven off from the plastics wire insulation by the heat generated during operation.

In addition to cubical shapes, two sizes of wafer shapes are presently being produced. One is approximately $\frac{1}{8}$ in. thick and $1\frac{1}{4}$ in. in dia; the other is about $\frac{3}{8}$ in. thick and $1\frac{1}{2}$ in. in dia. Expected to find wide use in the adsorption of unwanted odors and vapors, the wafers are designed to fit into the caps of small and large pharmaceutical bottles. The wafers can also be used for odor control in packages of potato chips and similar products.

High Strength Metals Formed by Explosives

The Air Force is backing a new method for shaping, forming and punching metals by the use of explosives. Basically, explosive forming releases energy by a powder charge or detonant at such a high rate that the metal is punched or formed "before it knows what happens." Explosive forming can be used to fabricate metals that cannot be formed in presses or other forming devices.

Current experiments indicate that cartridge-actuated devices may be used to punch holes in high strength alloys; to flare and bulge tubing; to form "nonformable" alloys of stainless steel; to avoid springback in forming titanium alloys; and to swage, upset and cup materials that cannot be formed by any other method.

Recently, Lockheed Aircraft Corp. in cooperation with the Air Force set up an explosives research program that encompasses three phases: 1) punching holes, 2) pressure forming with low explosives, and 3) pressure forming with high explosives.

In punching holes, Lockheed

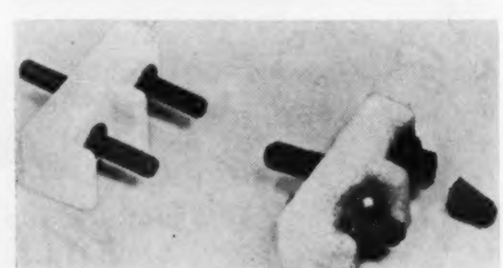
For more information, turn to Reader Service card, circle No. 393

What's new IN MATERIALS

uses a converted stud driver of the type currently used to sink fastening devices into concrete. The device is described as a captive piston gun actuated by .22 caliber stud driver shells. Lockheed engineers have punched holes in sheet steel of 250,000 psi tensile strength without cracking the surrounding metal.

Low explosive forming is accomplished in an enclosed chamber using a powder charge as the pressure source (low explosives burn rather than explode). Charges vary from slow blasting powder to high velocity pistol powder. The company has been using a firing head and 8-gage shells (1 in. dia) loaded with smokeless powder to expand tubing and form it into various shapes. According to Lockheed engineers, pressures up to 50,000 psi are safe with the present equipment.

High explosive forming is accomplished in a chamber that consists of a cupping die and a firing chamber. The explosive is detonated inside the chamber by the shock of a primary explosive a



Hot part—At left is an aircraft terminal block molded of synthetic mica the way it usually looks; at right is the same part after being accidentally exposed to a temperature of 1600 F. The synthetic mica retains its shape and is still firmly bonded to the remains of the steel inserts. The top operating temperature of the synthetic material, called Supramica 560 and available from Mycalex Corp. of America, is normally about 950 F.

SPECIAL REPORTS ON FINISHING NON-FERROUS METALS

NUMBER I—Decorative, Corrosion-Resistant Finishing with Iridite

Chromate conversion coatings are well known and accepted throughout industry as an economical means of providing corrosion protection, a decorative finish or a good paint base for non-ferrous metals. However, continued developments are so rapid and widespread that many manufacturers may not be completely aware of the breadth of application of this type of finish. Hence, this digest of current information; to bring you up to date on the many ways in which you can combine salable appearance with durability in one finish at a competitive price advantage. Report II on paint base, corrosion-resistant finishes and Report III on chemically polished, corrosion-resistant finishes are available on request.

First, as a basis for this discussion, a "decorative" finish is considered as any chromate film that is used as a final finish in itself. It may be truly decorative in that its sole purpose is to enhance the beauty of the product. For example, a bright chrome-like finish or a pleasing bronze appearance are among the many effects that can be obtained. It may be functionally decorative in that it reduces reflectivity for camouflage purposes or provides a means of color-coding parts. But, in all cases, the Iridite films protect the metal against corrosive attack.

Iridite finishes are now available for all commercial forms of the more commonly used non-ferrous metals, including zinc, cadmium, aluminum, magnesium, silver, copper, brass and bronze. These films can produce a wide variety of pleasing appearances. The basic colors of the Iridite coatings are grouped below by metals.

ZINC and CADMIUM: Metallic bright, light iridescent, iridescent yellow, bronze, olive drab.

COPPER, BRASS, BRONZE: Metallic bright, yellow.

ALUMINUM ALLOYS: Clear, iridescent yellow, brown.

MAGNESIUM ALLOYS: Light brown, dark brown, black.

SILVER: Metallic bright.

In addition, many films can be modified by bleaching or by dyeing. Among the dye colors available are various shades of red, yellow, green, blue or black.

Depending upon the metal and the Iridite used, corrosion resistance of clear and bright films ranges from mild passivity to as high as 500 hours in salt-spray; on heavier dark films, salt-spray resistance ranges from approximately 100 to 1000 hours.

It is this combination of decorative and corrosion resistant properties that accounts for the widening use of Iridite finishes. For example, Iridites #4-73 and #4-75 (Cast-Zinc-Brite) make possible for the first time, a combination of lustrous chemical polishing of the as-cast surface of zinc die castings and good resistance to corrosion. Further, in many cases, sizeable savings in the cost of buffing and electroplating are realized.

WHAT IS IRIDITE®?

Briefly, Iridite is the tradename for a specialized line of chromate conversion finishes. They are generally applied by dip, some by brush or spray, at or near room temperature, with automatic equipment or manual finishing facilities. During application, a chemical reaction occurs that produces a thin (.00002" max.) gel-like, complex chromate film of a non-porous nature on the surface of the metal. This film is an integral part of the metal itself, thus cannot flake, chip or peel. No special equipment, exhaust systems or specially trained personnel are required.

On many steel parts, a simple system of zinc or cadmium plate and bright Iridite is used instead of more costly electroplated finishes to provide a bright, decorative and protective finish with tremendous savings in material, equipment and labor.

In finishing aluminum, where corrosion resistance or paint adherence is the prime consideration, the aircraft industry has all but abandoned the anodizing process in favor of recently developed chromate conversion coatings, among them Iridite #14 and #14-2 (Al-Coat). These formulations and their method of application can be varied to retain the original metallic appearance while providing acceptable corrosion resistance, or to produce a fully colored brown finish that offers exceptional corrosion protection. Again, time and manpower savings are astounding—one company saved at least $15,000 a year on maintenance of racks alone and another $40,000 on materials and labor in only nine months. In addition, of course, hundreds of thousands of dollars are saved by eliminating the need for expenditures for generators, heating equipment and racks.

Iridites are widely approved under both Armed Services and industrial specifications because of performance, low cost and savings of materials and equipment.

In planning or designing, you should consider the many other characteristics of Iridite finishes which may enter into the specific problem. In addition to having decorative and protective functions, these chromate coatings form an excellent base for organic finishes and bonding compounds. They have low electrical resistance. Some can be soldered and welded. The Iridite film itself does not affect the dimensional stability of close tolerance parts.

You can see then, that with the many factors to be considered, selection of the Iridite best suited to your product requires the services of a specialist. That's why Allied maintains a staff of competent Field Engineers—to help you select the Iridite to make your installation most efficient in improving the quality of your product. You'll find your Allied Field Engineer listed under "Plating Supplies" in your classified telephone book. Or, write direct and tell us your problem. Complete literature and data, as well as sample part processing, is available. Allied Research Products, Inc., 4004-06 E. Monument Street, Baltimore 5, Maryland.

(Adv.)

For more information, turn to Reader Service card, circle No. 364

few inches above the metal to be formed. Lockheed says, "With high explosive forming, hardened type 302 stainless steel has been formed far beyond the elongation achieved with conventional forming methods."

Mica-Silicone Insulation

Mica paper impregnated with a silicone resin is available in thicknesses of 0.002 to 0.010 in. from Spruce Pine Mica Co., Flexi-Mica Div., Spruce Pine, N. C. Said to be a low cost Class H insulation, the material has a dielectric strength of 500 to 800 v per mil, depending on type of impregnation, and a tensile strength (unsupported) of 10,000 psi. According to the producer, present production is limited to 12 x 24-in. sheets, with 36 x 36-in. sheets scheduled for production early this year.

Ground Die Steel Is Made Oversize

A flat ground die steel, designated "Select B FM oversize ground," has been introduced by Latrobe Steel Co., Special Products Div., Latrobe, Pa. It is an air hardening steel containing 25% chromium with added sulfide particles and is manufactured oversize by 0.010 to 0.012 in. so that it may be ground to nominal dimensions after heat treatment. The product is available from stock in sizes ranging from 1/4 x 1 ft to 2 x 8 ft in lengths from 18 to 36 in.

Correction

The address given for Owens-Corning Fiberglas Corp. in the Nov '57 issue, p 182, l 10, is incorrect. It should read 598 Madison Ave., New York 22.

MATERIALS AT WORK

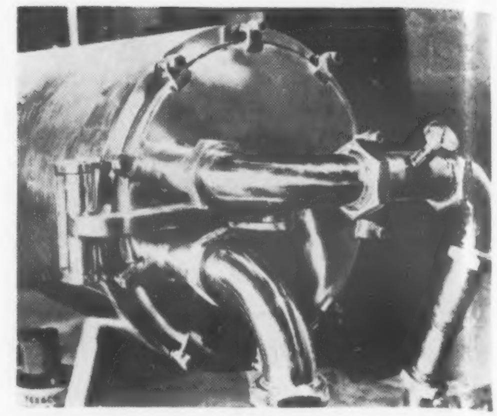
Orange juice—cont'd from p 12

The body, cover and impeller of each of these pumps are made of ACI type CF-8M stainless steel (see accompanying table for composition). This alloy was chosen because of its resistance to citric acid and the ease with which it can be cleaned with a strong alkaline detergent. To regulate flow of juice from the various tanks, hand operated shut-off valves made of CF-8M are used.

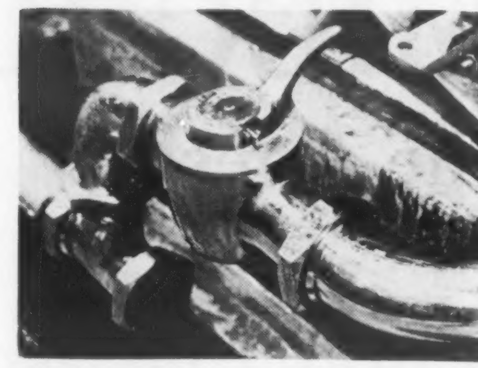
As the orange juice is pumped from the ship to the receiving plant, the temperature of the juice rises one or two degrees. To bring it down to the necessary 29 F, the juice is pumped through a chiller. At each end of the chiller are two heads made of CF-20 stainless steel castings.

After chilling, the juice is pumped into ten refrigerated stainless steel tanks, each of which is 60 ft long, 8 in. dia and holds 25,500 gal. Because storage capacity is less than the quantity of juice brought by the ship, continuous removal from the tanks to packaging machines must be maintained. The juice is conveyed from the tanks to the machines through stainless steel piping.

The packaging machines, made by American Can Co., are designed with a cast stainless collecting bowl from which the juice is measured into each container. The bowl is made of CF-16F stainless alloy. This alloy was selected because of the ease with which milling, turning, drilling and boring could be performed.



***Headers** collect orange juice at each end of chiller tank.*



***Plug valves** regulate flow of juice out of storage tanks.*

COMPOSITION OF THREE STAINLESS ALLOYS, (%)

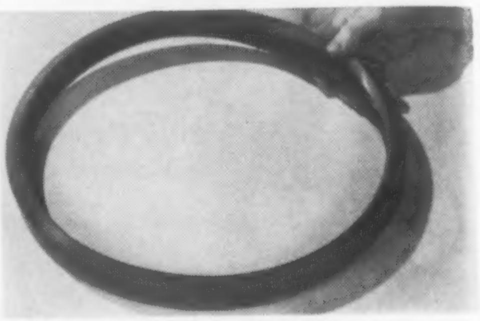
Alloy Type ➜	CF-8M	CF-20	CF-16F
C	0.08	0.20	0.16
Ni	9-12	8-11	9-12
Cr	18-21	18-21	18-21
Mo	2-3	—	1.5
Se	—	—	0.20-0.35

Silicone Seal Stops Costly Leaks

The switch from conventional rubber seals to silicone rubber couplings in the coal handling lines of Consolidated Edison Co.'s huge boilers has eliminated the necessity for frequent replacement due to failure.

To accommodate the expansion and contraction of the huge boilers, a total of 234 flexible

MATERIALS AT WORK



Flexible couplings *made of silicone rubber have long life.*

couplings—one every 10 ft—are used in the coal handling lines running from the ball mills to boiler fireboxes. Temperature of the preheated, pulverized coal in these lines is around 150 F. However, ambient temperatures, especially near the boilers, range as high as 325 F. As a result, life

Largest wire rope sling—Shown above is what is claimed by Jones & Laughlin Steel Corp. to be one of the largest endless wire rope slings ever produced. The wire rope in the huge grommet slings is 3 in. in dia and contains more than 1700 wires. The sling is 93 ft in circumference and was made with more than 700 ft of 1-in. wire rope. The sling weighs approximately 1700 lb and is designed to handle 300-ton lifts.

of the previously used seals was limited to an average of six months, with occasional failures occurring within as little as a week. And, although the seals themselves cost little, labor costs for replacements ranged from $50-100 each.

The silicone rubber seals, made from Dow Corning Corp.'s Silastic, have been in place for over a year; as yet not a single one has had to be replaced.

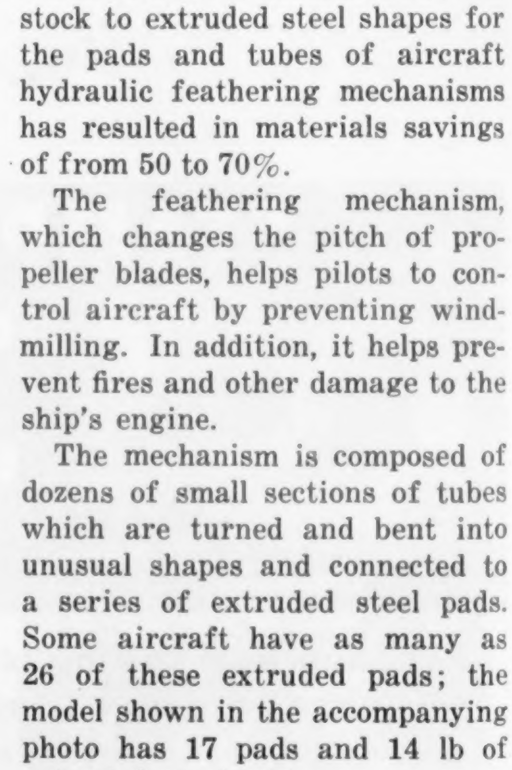
Extruded Steel Parts Help Control Aircraft

The switch from fabricated bar stock to extruded steel shapes for the pads and tubes of aircraft hydraulic feathering mechanisms has resulted in materials savings of from 50 to 70%.

The feathering mechanism, which changes the pitch of propeller blades, helps pilots to control aircraft by preventing windmilling. In addition, it helps prevent fires and other damage to the ship's engine.

The mechanism is composed of dozens of small sections of tubes which are turned and bent into unusual shapes and connected to a series of extruded steel pads. Some aircraft have as many as 26 of these extruded pads; the model shown in the accompanying photo has 17 pads and 14 lb of extruded steel tubing.

In addition to reducing weight,



Allegheny Ludlum Steel Corp.
***Feathering mechanism** used to control aircraft.*

the use of steel extrusions has minimized hydraulic leaks and the system is capable of operating under pressures of 3000 psi.

Unusually Large Valve Is Made of Cast Steel

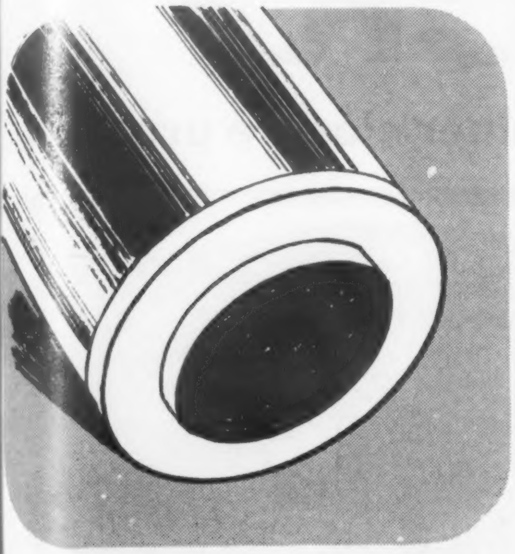
Two diaphragm control valves, each made of nearly two tons of cast steel and requiring 155 hr to machine, have been installed by Minneapolis-Honeywell Regulator Co. in Philadelphia Electric Co.'s Edison plant. The 16-in., 9½-ft high valves, the largest ever produced by Minneapolis, will control the flow of steam to distribution mains throughout the city.

Each valve will control a maximum flow of 400,000 lb of steam at 450 F under pressures of 160 psi per hr. According to Minneapolis, the valves are unusual in that their mouth openings are about 12 in. wider than most other industrial control valves. Internal moving parts are of stainless steel.

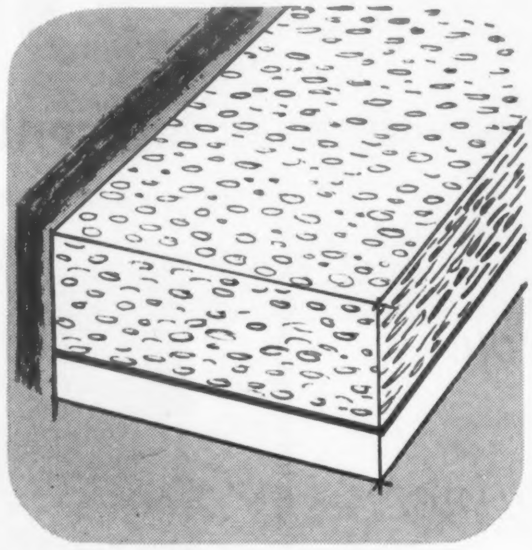
***Two-ton cast steel valve** has 16-in. mouth opening.*

PROPERTIES of most engineering materials can be found in M/DE's *Materials Selector* reference issue, published last September. Names and addresses of suppliers are also listed.

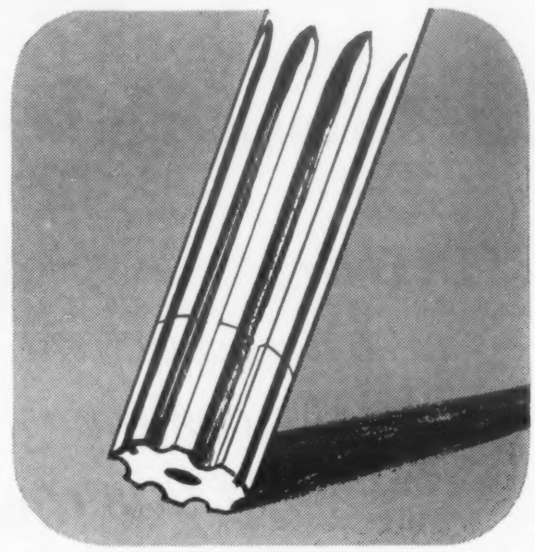
NOW—improved production through faster and better bonding with R/M Ray-BOND® Adhesives



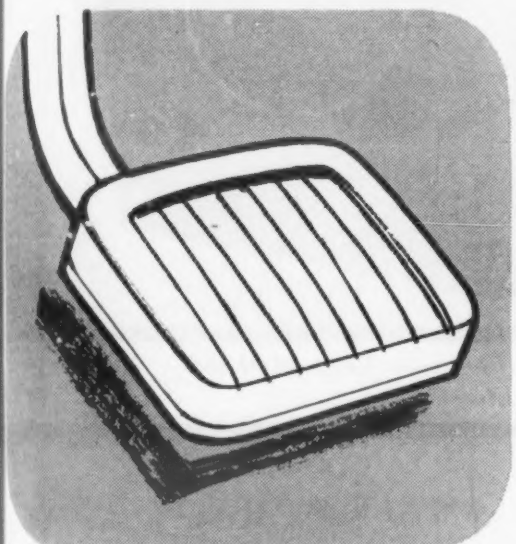
Butyl rubber foot to stainless steel tank



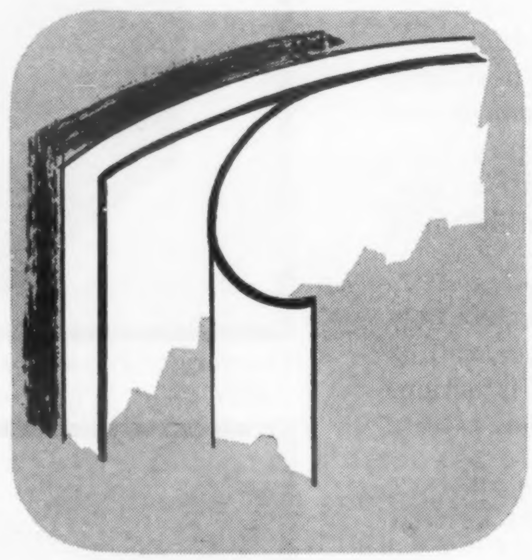
Synthetic foam to metal



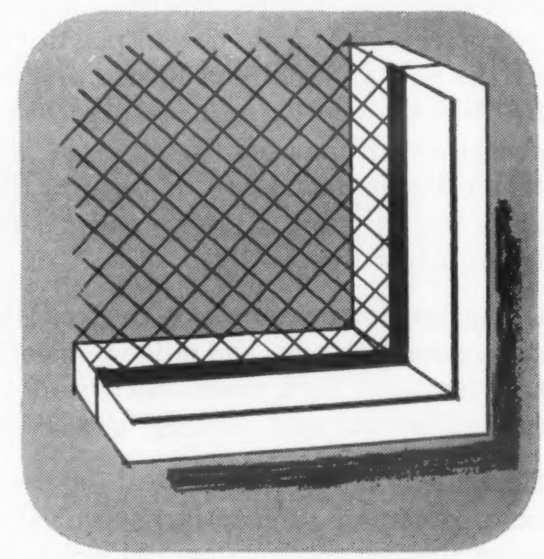
Ceramic tips to steel shanks



Natural rubber to clutch pedal



Etched "Teflon"* to steel



Rubber seals to stainless steel screens

FOR THESE AND COUNTLESS OTHER APPLICATIONS

NEW R/M Ray-BOND ADHESIVES CAN BE TAILORED TO YOUR NEEDS

Whether or not bonding, laminating, sealing or coating are now factors in your operations, the new specialized line of R/M Ray-BOND adhesives, protective coatings, and sealers may have important advantages for you. Shown above are a few of thousands of applications where use of modern bonding techniques can simplify and improve product design and eliminate troublesome fastening problems.

R/M initiated the production of bonded assemblies more than 20 years ago. Over the years we have acquired a wealth of experience that can help you cut costs and simplify operations in innumerable bonding applications. Call on our engineers to work with you in developing adhesives, protective coatings, and sealers to meet your specific requirements. Adhesives Department, RAYBESTOS-MANHATTAN, INC., Bridgeport, Conn.

Send for free copy of R/M Bulletin No. 650A, containing engineering information on Ray-BOND adhesives, protective coatings, and sealers.

*A Du Pont trademark

RAYBESTOS-MANHATTAN, INC.

ADHESIVES DEPARTMENT: Bridgeport, Conn. • Chicago 31 • Detroit 2 • Cleveland 16 • Los Angeles 58

FACTORIES: Bridgeport, Conn.; Manheim, Pa.; Passaic, N.J.; No. Charleston, S.C.; Crawfordsville, Ind.; Neenah, Wis.; Raybestos-Manhattan (Canada) Limited, Peterborough, Ontario, Canada

RAYBESTOS-MANHATTAN, INC., Industrial Adhesives • Brake Linings • Brake Blocks • Clutch Facings • Industrial Rubber • Engineered Plastics • Sintered Metal Products Rubber Covered Equipment • Asbestos Textiles • Laundry Pads and Covers • Packings • Abrasive and Diamond Wheels • Bowling Balls

For more information, turn to Reader Service card, circle No. 498

Note—Commercial and Military Packaging Engineers:

LINK-LOCK

...is the rugged answer to your exacting container closure problems

Courtesy of Pressurform Container Corp., and the LMEE Dept. of General Electric Co.

LINK-LOCK plays an important role in the design of this container

Simmons' LINK-LOCK provides pressure-tight, impact-resistant closure, plus quick closing and opening, on this reinforced fibrous plastic product made by the new automatic pre-form process developed by Pressurform Container Corp. The two-section container will be used by the Light Military Electronic Equipment Dept. of General Electric Company for shipping airborne radar jamming units to the Air Force.

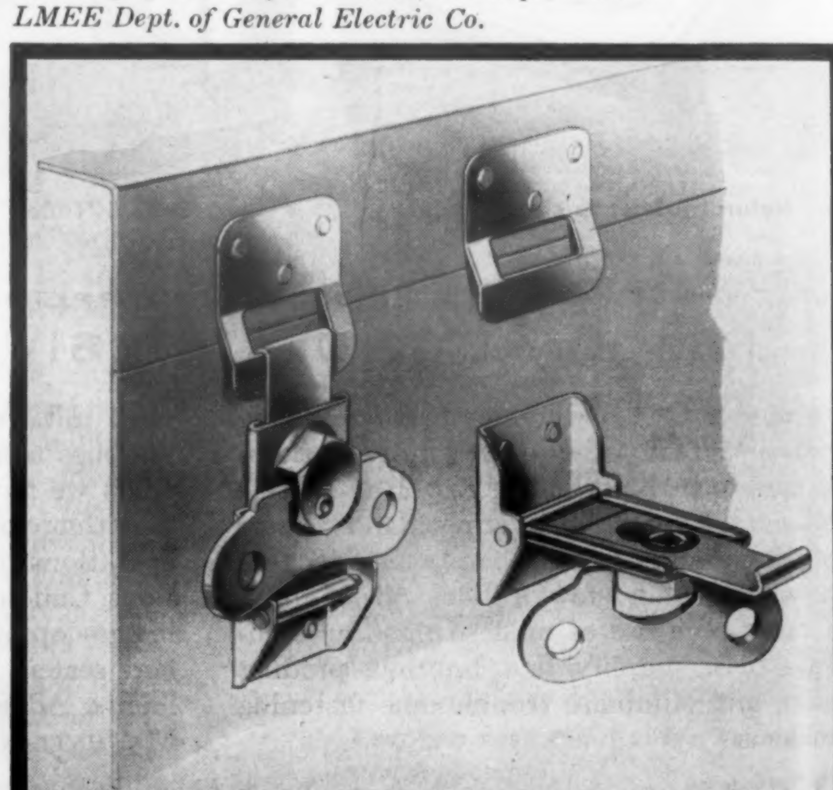
Of prime importance are the container's lightness, strength, rust- and mildew-resistance, ability to withstand high pressures without distortion, ease of locking and opening, and low cost.

Here's why LINK-LOCK is ideal for use on military cases produced to exacting specifications as well as on inexpensive commercial containers:

- High closing pressure with light operating torque... insures pressure-tight seals where required.
- Impact and shock resistant (positive-locking).
- Compact design...lays flat against case even when unlocked.
- Available in 3 sizes, for heavy, medium, and light duty.
- Opening and closing by wing-nut, screwhead, or hex nut.
- Flexible engagement latch design...can be varied to suit different conditions.

Also available! Spring-Loaded LINK-LOCK... ideal for less expensive containers where costs won't permit precision production. Spring provides take-up to compensate for set in gasketing, irregularities of sealing surfaces, and mounting inaccuracies.

Where does the versatile Simmons LINK-LOCK belong in your design? For full information and specifications, send for LINK-LOCK DATA SHEETS today. Samples and engineering service available upon request.



SIMMONS
FASTENER CORPORATION

1759 North Broadway, Albany 1, New York

QUICK-LOCK SPRING-LOCK ROTO-LOCK LINK-LOCK DUAL-LOCK

See our 8 page catalog in Sweet's 1958 Product Design File.

For more information, turn to Reader Service card, circle No. 425

PRICES AND SUPPLY

...AT A GLANCE

STEELMAKING CAPACITY IN THE UNITED STATES will increase by 10% within the next two years, according to a prediction by Lukens Steel Co. By 1959, the industry is expected to raise its annual capacity from the present 133.5 million tons to more than 146 million tons. Over the past seven years, the steel industry has increased capacity by nearly 20%.

A 50% INCREASE IN STEEL INGOT PRODUCTION within the next 20 years is forecast for Inland Steel Co. by Joseph L. Block, president. Based on a series of increases projected for five-year periods, the company's annual steel ingot production is scheduled to rise from a current level of 5,600,000 tons to 11,700,000 tons by 1977.

WIDE FLANGE STEEL BEAM OUTPUT is also scheduled for an increase by Inland Steel Co. According to recently announced plans, the company intends to up its production from 28,000 tons per month to 54,000 tons per month early in 1959. The wide flange beam, a compact "H" shape, is said to provide the greatest strength per unit of weight of any structural section used in construction.

STEEL PRICES STILL A QUESTION. Steelworkers' wage rates are about to be increased approximately 4¢ per hr as a result of cost-of-living provisions in their contracts. Steel companies hiked their prices $6 per ton following a 20¢ boost in hourly pay last July. The question of additional price increases early this year is slightly complicated, however, by lagging demand for steel, and steel producers have been debating the question since last November.

DU PONT'S NEW TEFLON 100-X PERFLUOROCARBON RESIN (see MATERIALS & METHODS, Nov '56, p 162) is now being molded and extruded in limited quantities by United States Gasket Div., Garlock Packing Co. Among the products announced as available are: monofilaments from 5 mils; rods to 2 in. in dia; tubing from 10 mils to 3/8 in. o.d. with wall thicknesses of a few mils and higher; and high grade electrical tape from 1/2 mil to 1/16 in. in thickness and in widths up to 24 in.

PRICE REDUCTIONS FOR MOLYBDENUM DISILICIDE AND SILICON NITRIDE—two refractory metal compounds--have been announced by Electro Metallurgical

Co., Div. of Union Carbide Corp. Price of molybdenum disilicide powder of 150 mesh was reduced from $15 to $12 per lb for quantities of more than 50 lb. Silicon nitride powder of 150 mesh is now $1.65 per lb, down from $2.00.

MORE HIGH DENSITY POLYETHYLENE will be available when Union Carbide Corp.'s new Whiting, Ind. plant is completed in the first half of 1959. The new plant, with a rated capacity of 72 million pounds, will raise Union Carbide's total rated annual polyethylene production capacity to more than 375 million pounds.

AND MORE INTERMEDIATE DENSITY POLYETHYLENE—a material with properties somewhere between those of conventional polyethylene and the high density type—will also be available. National Petrochemicals Corp. is planning the construction of a new plant which will increase its annual intermediate polyethylene production by 75 million pounds. The new plant, to go on stream late this year, will raise the company's total polyethylene capacity to 175 million pounds.

COMMERCIAL PRODUCTION OF DELRIN, Du Pont's new acetal resin, is expected to begin by mid-1959. The material, presently being tested in a number of applications including automobile parts, industrial machinery, packaging, electrical equipment and appliances, pipe, and plumbing fixtures, is expected to sell at a price "under $1 per lb." (For technical details of this new resin, see p 155.)

MORE NICKEL WAS AVAILABLE FOR CONSUMPTION DURING 1957 than in any other year in the commercial history of nickel, according to J. Roy Gordon, vice president, International Nickel Co. of Canada, Ltd. And the chances are that there will be even more nickel available in 1958 than there was in 1957.

AN INCREASE IN THE PRICE OF PLYWOOD may be in the offing, according to Owen R. Cheatham, chairman of Georgia-Pacific Corp. Mr. Cheatham explains that consumption has been running about 10% higher than production for the past few months ". . . leading to the belief that a higher price for the material can be supported."

PRODUCTION OF URANIUM OXIDE is expected to double by 1959, according to the U.S. Atomic Energy Commission. Free world production in 1957 was about 21,000 tons, and the estimate for 1959 is in excess of 40,000 tons, with the U.S. and Canada accounting for more than 30,000 tons. Domestic uranium ore reserves are estimated to be about 70 million tons, rated at about 5 lb of uranium oxide per ton.

Prices of Materials

Changes since last month are bold-faced

NONMETALLICS

Prices for large quantities for range of grades, color, sizes; given in $/lb

RUBBER

Material	Dry	Latex
Butadiene-Acrylonitrile	.49-.65	.46-.54
Butadiene-Styrene	.17-.30	.22-.32
Butyl	.23-.28	—
Neoprene[a]	.39-.75	.37-.47
Silicone[a]	1.90-4	—
Polysulfide[a]	.47-1	.70-.92
Natural	.28[b]	—

[a]Less than carload quantities.
[b]Average spot price for month of Nov.

GLASS FOR REINFORCED PLASTICS

Fabric ($/yd 38 in. wide)[a]	
112 Woven	.48
181 Long-shaft satin weave	1.03
143 Unidirectional	1.00
Roving[a]	
Continuous	.40
Continuous spun strand	.36
Continuous chopped spun	.38
Milled fibers (1/32-¼ in.)[a]	.45
Mat	
Chopped strand (2 in.)[a,b]	.52-.72
Surfacing ($/1000 sq ft)[c]	10-19
Continuous chopped strand (¼-2 in.)	.40

[a]Price includes binder or finish.
[b]Price varies with binder.
[c]0.010-0.020 in. thick.

THERMOSETTING PLASTICS

Material	Molding Compounds	Laminating, Casting Resins
Alkyd	.34-.53	—
Epoxy	—	.45-.80
Melamine	.42-.45	.40-.41
Phenolic	.21-.40	.17-.34
Polyester	.42	.32-.50
Silicone	2.75-5.40	1.55-1.74[a]
Urea	.19-.33	—

[a]60% solids content.

All prices are approximate and given solely for general guidance of those responsible for materials selection.

THERMOPLASTICS

Material	Molding Compounds	Sheet (.030-.250 in.)	Rod		Tube	
			⅛-¼ in.	⅜-1¼ in.	⅛-¼ in.	⅜-1¼ in.
Acrylic	.51-.59	.49-2.15	.90-1.15	.80-.90	1-1.15	.90-1
Cellulosic						
Acetate	.36-.65	.92-1.16	.75-1	.65-.75	.85-1	.75-.85
Butyrate	.50-.72	1-1.28	.95-1.20	.85-.95	1.05-1.20	.85-1.05
Nitrate	—	1.60-2.73	1.45-1.75		2.25-5.00	
Propionate	.51-.63	—	—		—	
Fluorocarbon						
CFE	7-8	15-23	18-22	14-20	20-22.50	16-20
TFE	4.50-7.45	14.30-11	13	13	13	13
Nylon	1.18-2.30	—	3	3	3	3
Polyethylene	.35-.56	.85-1	.75-1	.65-.75	.85-1	.75-.85
Polystyrene	.26-.44	.57-.61	.65-.90	.55-.65	.75-.90	.65-.75
Vinyl	.27-.43	.62-.92	.75-1	.65-.75	.85-1	.75-.85

NONFERROUS METALS

Mill base prices for large quantities; given in $/lb except where indicated

ALUMINUM

Pig (99-99.9%)	.26-.28
Ingot (99-99.9%)	.28-.30
Foil (5-0.5 mil)	.55-.77
Alloy Ingot (13, 43, A132, 214)	.29-.32
Sheet (1100, 3003; 3-0.03 in.)[a]	.43-.47
Plate (1100, 3003, 5050, 3004, 5052)[a]	.40-.43

[a]Mill finish.

BRASS

Form	Cart., 70%	Low, 80%	Red, 85%
Sheet, Strip	.44	.47	.47
Seamless Tubing	.47	.49	.50
Rod (not f.c.)	.44	.46	.47
Wire	.45	.47	.48

COPPER

Ingot (elec)	.27
Sheet, Strip (hot rolled)	**.50**
Seamless Tubing	**.50**
Rod, Drawn	.47
Rod, Free Cutting	.57
Wire	
Round	.32
Square, Rectangular	.35
Magnet	.40

LEAD

Common Grade	.135

MAGNESIUM

Pig (98.8%)	.35-.36
Ingot (98.8%)	.36-.37
AZ91B Ingot (die casting)	.37
AZ91C Ingot (sand casting)	.41[a]

[a]Delivered price.

NICKEL

Form	"F"	"A"	Monel
Ingot	.75[a]	—	—
Rod	—	1.07	.89
Sheet, C.R.	—	1.26	1.06
Strip, C.R.	—	1.24	1.08
Seamless Tube	—	1.57	1.29

[a]Delivered price.

TIN

Primary[a]	**.90**

[a]Delivered price.

(continued on p 186)

PRICES AND SUPPLY

TITANIUM

Sponge (99.3+%)	**1.65-2.50**
Bars, Rod	6.15-6.40
Plate	8.00-10.75
Sheet, Strip	**9.50-11.10**
Wire	7.50-8.00

ZINC

Prime Western	.10½ [b]
Die Casting Alloys [a]	**.14-.15**
Sheet	.24
Ribbon	.21
Plates	.19

[a]Alloys 2, 3, 5. [b]Delivered price.

METAL POWDERS

Aluminum [a,b]	.40
Brass [a]	**.31-.38**
Copper (elec or red.) [a]	**.41**
Molybdenum (98%)	3.80-4.10
Nickel	1.05
Tantalum	49
Tungsten (C-red. 98.8%; H_2-red. 99+%)	**3-4** [c]
Zirconium	
Flash Grade	11.50
Electronics Grade	15

[a]Price for —100 mesh. [b]Freight allowed. [c]Delivered price.

OTHER NONFERROUS METALS

Cadmium (bars)	1.70
Columbium	55-85
Gold	$35/troy oz
Indium (99.97+%)	$2.25/troy oz
Manganese (99.9%)	.34 [a]
Palladium	$23-24/troy oz
Platinum	$82-87/troy oz
Silver	91¢/troy oz
Tantalum (sheet, rod)	55-60
Vanadium	80
Zirconium (sheet, strip, bar)	27-35

[a]Delivered price.

IRONS AND STEELS

Mill base prices for large quantities

SEMIFINISHED STEEL ($/net ton)

Ingots, Alloy	77
Billets, Blooms, Slabs	
Carbon, Re-Rolling	77.50
Carbon, Forging	96
Alloy, Forging	114
Seamless Tube Rounds	117.50
Wire Rods	$6.15/cwt

(continued on p 188)

For more information, turn to Reader Service card, circle No. 449

PRICES AND SUPPLY

FINISHED STEEL ($/cwt)

Form	Carbon	High Str Low Alloy	Alloy
Plate	5.10	7.62	7.20
Sheet, H.R.	4.92	7.27	—
Sheet, C.R.	6.05	8.97	—
Strip, H.R.	4.92	7.32	8.10
Strip, C.R.	7.15	10.65	—
Bar, H.R.	5.42	7.92	6.47
Bar, C.F.	7.30	—	8.77

STAINLESS STEELS ($/lb)

Material	Forging Billets	H. R. Bars	Plate	Sheet, Strip
Austenitic				
301, 302, 302B, 303, 304, 305	.38-.41	.44-.48	.46-.51	.51-.59
321[a]	.47	.56	.60	.66
347[a]	.56	.65	.70	.80
Martensitic				
410[a]	.28	.34	.35	.40
416	.29	.34	.35	.47
403	.32	.38	.40	.48
420, 440	.34	.41	.45	.62
Ferritic				
405, 430, 430F[a]	.30	.34-.35	.36-.38	.41-.47
442	.32	.38	.40	.56
431	.30	.35	.46	.54
446	.38	.45	.46	.67
High Mn				
202[a]	.37	.43	.45	.49
Extra Low C				
304L	.48	.56	.59	.63
316L	.70	.81	.85	.89
Precip Hard.				
17-7PH	.66	.73	.85	.90

[a]Ingot prices approx 60% of forging billet price.

METAL POWDERS ($/lb)[a]

Sponge Iron	.10-.11
Electrolytic Iron	
Annealed (99.5%)	.37
Unannealed (99+%)	.36
Stainless Steel	
304	1.02
316	1.20

[a]Price for —100 mesh.

IRON ($/gross ton)

Pig	65-66

(continued on p 190)

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PRICES AND SUPPLY

CLAD STEELS (¢/lb)[a]

Cladding Metal	10%	15%	20%
Stainless			
304	37.95	42.25	46.70
304L	40.55	45.10	49.85
316L	49.35	54.70	60.10
321	40.05	44.60	49.30
347	42.40	47.55	52.80
430	29.80	33.35	37.25
Inconel	59.55	70.15	80.85
Nickel	51.95	62.30	72.70
Monel	53.55	63.80	74.05

[a]Prices given for three cladding thicknesses.

TIN PLATE ($/base box)

Hot Dip (1.25-1.50 lb)	10.05-10.30
Electrolytic (0.25-0.75 lb)	8.75-9.40

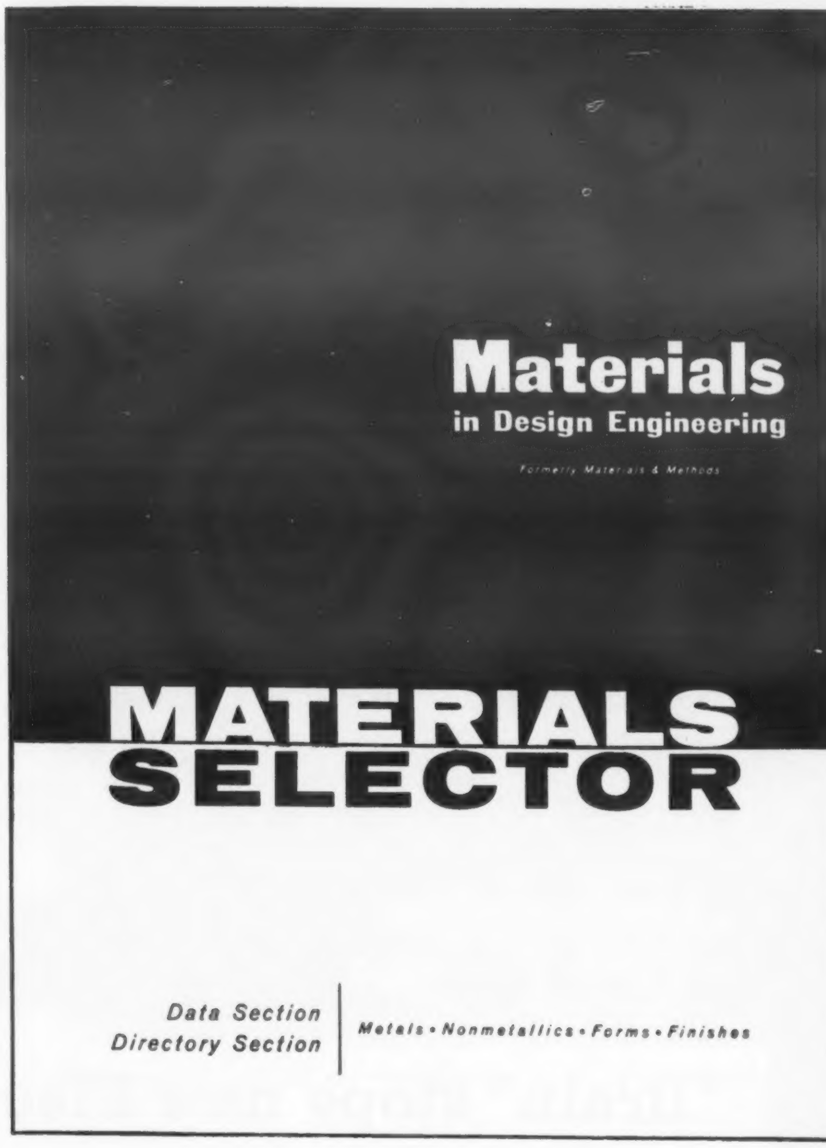
FINISHES AND COATINGS

ORGANIC COATINGS

Material	Avg Thk per Coat, mil	Mils Required[a]	Cost, ¢/sq ft/dry mil[b]
VARNISHES, ENAMELS			
Short Oil Phenolic			
Varnish	1.0	1.0	1.50
Enamel	1.2	1.0	1.75
100% Phenolic	1.0	1.5	1.75
Straight Oil-Modified			
Alkyd	1.5	1.5	1.50
Alkyd-Amine (90-10)	1.5	1.5	1.75
Alkyd-Phenolic (50-50)	1.5	1.5	1.75
Alkyd-Vinyl (50-50)	1.0	2.0	2.0
Alkyd-Styrene (70-30)	1.2	1.5	1.75
Epoxy	1.8	1.8	2.00
Silicone	.5-1.0	.5-1.0	6.0
Furane	2.0	2.0	1.0
Neoprene	5.0	5.0	1.50
DISPERSION COATINGS			
Phenolic	1.0	1.5	1.75
Vinyl	1.0	2.0	2.50
Fluorocarbon	1.0	1.0	15.0
LACQUERS			
Nitrocellulose	1.0	2.0	2.50
Vinyl	1.0	2.0	2.50
Acrylic	1.0	2.0	2.75
Butyrate	1.0	2.0	2.75

[a]Thickness over phosphate coating required for exterior durability on steel. For purely decorative coating, 1 mil will usually suffice.
[b]Materials cost only. Realistic price comparison can be made only on basis of dry applied coating, not on basis of cost per gallon.

Keep this on your desk...



MATERIALS SELECTOR ISSUE

If you're a subscriber to MATERIALS IN DESIGN ENGINEERING you now have your copy of the 1957-1958 MATERIALS SELECTOR. If you keep the SELECTOR within easy reach and form the habit of using it regularly, you'll find it a time saver. Here are some of the reasons why. . . .

WHAT IT IS: All editorial pages of the MATERIALS SELECTOR are in data sheet form. These provide materials-specifying engineers, designers and other technical men with the most complete and best organized annual reference data available. It offers you two major editorial sections:

- **Data Section**
  - Comparisons of Materials
  - Properties of Materials
    - Irons and Steels
    - Nonferrous Metals
    - Plastics and Rubber
    - Nonmetallics *(except Plastics and Rubber)*
  - Finishes and Coatings
  - Forms and Shapes of Materials
- **Directory Section**
  - Suppliers of Materials *(classified by Materials, Forms, and Finishes)*
  - Addresses of Suppliers

WHY M/DE PUBLISHED IT: You and your fellow readers continually ask us for information of all sorts about materials selection. In fact, requests for further information resulting from MATERIALS IN DESIGN ENGINEERING's editorial and advertising pages average better than 225,000 per year! Until now, no one has ever attempted to consolidate reference data in a single annual issue and thus make it easier to determine the answers to the problems that confront you when you select and specify engineering materials.

WE'RE EXCITED because our readers have been given just what they want in the MATERIALS SELECTOR. Get into the habit of using it. We know you'll find it the most complete, the most useful, year-round reference issue published.

The Editors

Materials in Design Engineering

The MATERIALS SELECTOR *is not sold separately—available only by subscription to* MATERIALS IN DESIGN ENGINEERING.

Sealed glass vessel *filled with helium or argon is used in preparation of pure ingot.*

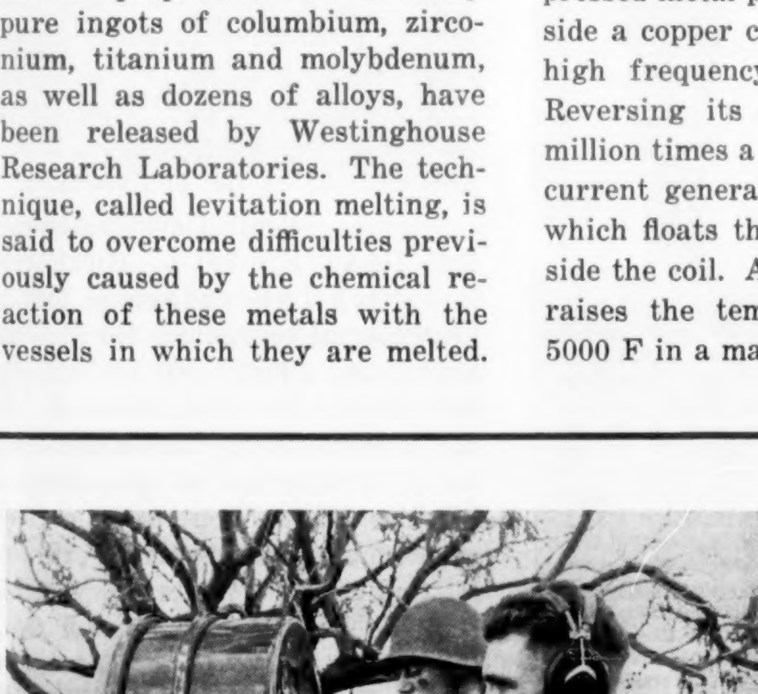
Close-up *shows coil surrounding white-hot molten metal.*

Ultra-Pure Metals Prepared by Levitation Melting

■ Further details on a technique for the preparation of extremely pure ingots of columbium, zirconium, titanium and molybdenum, as well as dozens of alloys, have been released by Westinghouse Research Laboratories. The technique, called levitation melting, is said to overcome difficulties previously caused by the chemical reaction of these metals with the vessels in which they are melted.

In levitation melting, compressed metal powder is placed inside a copper coil which carries a high frequency electric current. Reversing its direction nearly a million times a second, the electric current generates a field of force which floats the metal charge inside the coil. At the same time, it raises the temperature to 4000-5000 F in a matter of seconds and converts the metal into a white-hot molten mass.

Because the molten metal floats freely in space, no containing vessel is necessary and the possibility of picking up impurities is eliminated. Furthermore, the whole process is carried out inside a sealed vessel containing an inert gas such as helium or argon, thereby protecting the pure metal from contamination by air. West-



Union Carbide Corp.

Electricity from gases—Electrical power for the small portable radar set shown here is supplied from a group of fuel cells instead of conventional dry cell batteries. Designed to work at approximately atmospheric pressures, the new fuel cells are the first that do not depend on high temperatures or pressures for operation. The fuel cell is merely a sealed jar into which are fed hydrogen and oxygen through special hollow electrodes. The electrochemical reaction of the gases at these electrodes produces an electric current with water as a by-product. Since the water is disposed of by evaporation, the life of the fuel cell is said to be theoretically unlimited.

News OF INDUSTRY

inghouse scientists report that the molten metal even stirs itself.

Because it is now possible to prepare extremely pure columbium and columbium-base alloys, Westinghouse suggests that research may take this metal out of the laboratory and turn it into an outstanding high temperature, high strength structural metal.

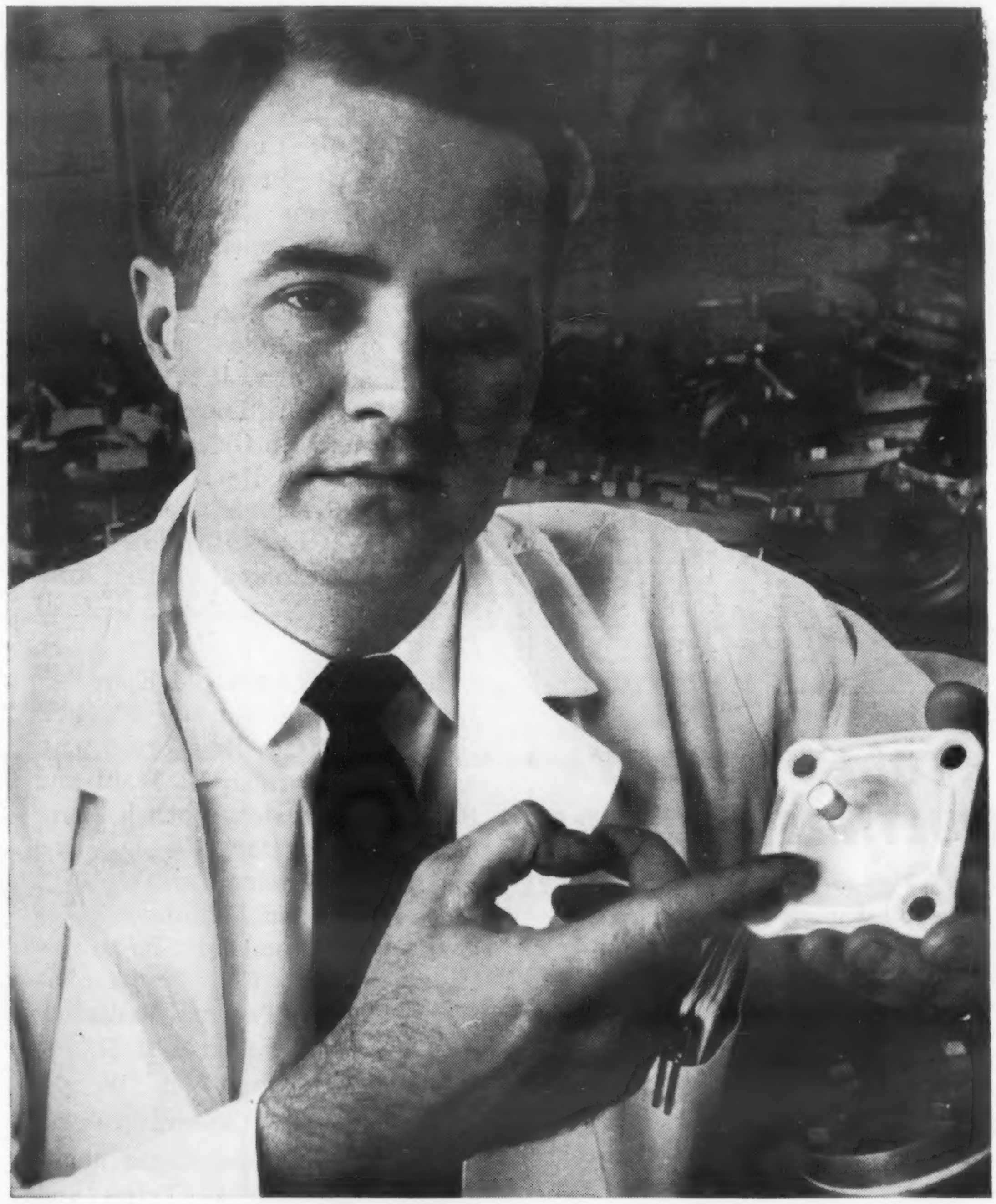
SPI To Hold Meeting on Reinforced Plastics

The program of the 13th conference of the Reinforced Plastics Div. of the Society of the Plastics Industry, Inc. is aimed at providing designers, engineers and businessmen with the information that SPI believes is necessary for reinforced plastics to "continue their growth in both volume and variety of products." The three day conference, to be held Feb 4-6 at the Edgewater Beach Hotel in Chicago, is divided into 18 half-day sessions devoted to materials, materials performance, methods of production, product design and product application. Here is a partial list of papers scheduled for presentation at the conference:

"Survey—Resin Developments," Dr. Johan Bjorksten, Bjorksten Research Laboratories, Inc.; "Functional Inorganics for Use as Reinforced Plastic Fillers," S. R. Mountsier, Jr., and Miss A. J. Gitter, Whittaker, Clark & Daniels, Inc.; "Properties of Reinforced Plastics Made From Acrylic Sirup," Mandell S. Ziegler, William H. Calkins and Walter Edwards, E. I. du Pont de Nemours & Co., Inc.; "Optimum High Strength Epoxy Laminates," Harry Raech,

SOURCES of most engineering materials can be found in M/DE's "Materials Selector" reference issue, published last September. Properties of all materials are also given.

Valve diaphragm of R/M TEFLON* helps speed production of polio vaccine!



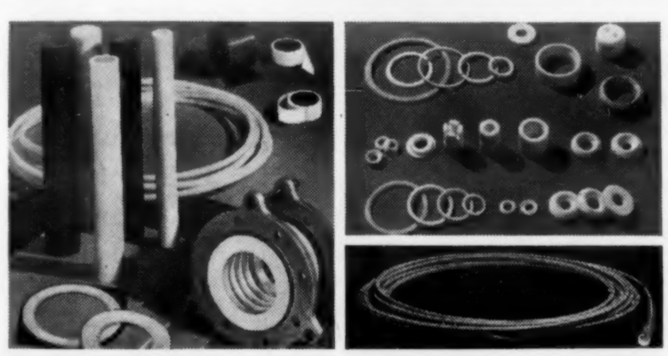
Here's how Raybestos-Manhattan co-operated with a customer to make possible faster production of vitally needed Salk polio vaccine.

Salk vaccine is 20 days in the making, requires another 110 for testing. During this time the portable processing tanks must be sealed off from all possibility of contamination. Processing temperatures range from 5 to 150°C. Diaphragm valves were chosen for this work because they make possible complete cleaning and sterilization.

The solid valve diaphragms originally used were unable to withstand the extreme operating conditions involved. R/M "Teflon" was selected for the task because of its strength, flexibility, chemical inertness, and capacity to endure—unchanged—the wide range of temperatures necessary.

R/M worked closely with the customer and promptly developed a new method of molding a "Teflon" valve diaphragm ideally suited to this exacting need. The new "Teflon" diaphragm was much thinner than the one formerly used, with improved flex life that permitted a greater number of manufacturing cycles—this without danger of valve failure at a critical point in the process.

*A DuPont trademark



Other R/M products for the chemical industry include flexible thin-wall "Teflon" hose; custom-machined parts; rods, sheets, tubes and tape; centerless ground rods held to very close tolerances; stress-relieved molded tubes and rods; gaskets, expansion joints, and flexible couplings; bondable tape and sheets for linings; Raylon (R/M trade name for mechanical grade "Teflon") which has many characteristics of virgin "Teflon."

R/M

RAYBESTOS-MANHATTAN, INC.

PLASTIC PRODUCTS DIVISION FACTORIES: MANHEIM, PA.; PARAMOUNT, CALIF.

Contact your nearest R/M district office listed below for more information or write to Plastic Products Division, Raybestos-Manhattan, Inc., Manheim, Pa.

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NEW ORLEANS 17 • PASSAIC • PHILADELPHIA 3 • PITTSBURGH 22 • SAN FRANCISCO 5 • SEATTLE 4 • PETERBOROUGH, ONTARIO, CANADA

RAYBESTOS-MANHATTAN, INC., Engineered Plastics • Asbestos Textiles • Mechanical Packings • Industrial Rubber • Sintered Metal Products • Rubber Covered Equipment
Abrasive and Diamond Wheels • Brake Linings • Brake Blocks • Clutch Facings • Laundry Pads and Covers • Industrial Adhesives • Bowling Balls

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Jr., Northrop Aircraft, Inc. and Fred Harris, Grand Central Rocket Co.

"Effect of Curing Conditions on Physical Properties," Grant Brown, Cordo Chemical Corp.; "Mechanical Properties of Glass-Reinforced Casting Resins," C. L. Segal, Hughes Aircraft Co.; "Bond of Resin to Glass," A. C. Anderson and Dr. J. H. Healy, A. O. Smith Corp.; "Long-Term Rupture Strength in Glass-Reinforced Plastics," S. Goldfein, U. S. Army Engineer Research and Development Laboratories; "Unidirectional Glass-Reinforced Plastic Ring Structures," N. Chessin, General Electric Co.

"Creep of Laminated Epoxies," John Delmonte, Furane Plastics, Inc.; "Laminates Reinforced with Asbestos," Norman E. Wahl and Harold M. Preston, Cornell Aeronautical Laboratory, Inc.; "Some Factors Influencing Durability of Glass-Reinforced Laminates," Arthur L. Smith and John R. Lowry, Rohm & Haas Co.; "Effects of High Intensity Thermal Radiation on Plastic Laminates," H. S. Schwartz and B. J. Lisle, Wright Air Development Center; "Effects of Elevated Temperatures above 500 F," Roland A. Tripp and Francis Bozzacco, Goodyear Aircraft Corp.

"Behavior of Reinforced Plastics at Very High Temperatures," L. H. Shenker and I. J. Gruntfest, General Electric Co.; "A Comparison of Phenolic and Polyester Premix Materials," J. J. Colao and M. M. Gurvitch, Barrett Div., Allied Chemical & Dye Corp.; "Physical Properties of Transfer and Compression Molded Premix Materials," R. H. Calderwood and H. R. Sheppard, Westinghouse Electric Corp.; "Applications and Suggested Uses of Polyester Premixes," C. W. Proudfit, Celanese Corp. of America.

(News of Engineers on p 198)

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Engineers

Dr. Clarence A. Stiegman is now technical director and **Dr. J. Howard Brown** general manager, Niagara research and development, Hooker Electrochemical Co.

Kenneth W. Bruland has been appointed superintendent of the new iron powder plant to be constructed by Alan Wood Steel Co.

Herbert R. Erickson has joined the Chemical Div., Borden Co., as development manager of the polyvinyl chloride extrusion dept.

Kenneth French is now manager, product development dept., Flexible Tubing Corp.

Edwin A. Martin has been appointed assistant general manager, Footwear and General Products Div., U.S. Rubber Co.

Cole Downing is now technical manager of the Acrilan plant, Chemstrand Corp.

H. A. Steinherz has been promoted to the position of manager of engineering and development, NRC Equipment Corp.

Companies

Pittsburgh Plate Glass Co. is building a multi-million dollar window glass plant near Decatur, Ill.

Instron Engineering Corp. is building a new 25,000-sq ft plant in Canton, Mass.

American Can Co. and **Marathon Corp.** have reached agreement on terms for a merger. Canco will acquire all of Marathon's assets and its subsidiaries.

Shell Chemical Corp. is building a new product development plant in Martinez, Calif.

Superior Steel & Malleable Castings Co. has completed a new addition to its Benton Harbor plant.

Reeves Soundcraft Corp. announces that it will build "the first plant de-

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For more information, turn to Reader Service card, circle No. 500

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signed specifically to meet modern requirements for the manufacture of magnetic tapes."

Central Screw Co. has opened a new 80,000-sq ft plant in Frankfort, Ky.

Arcflux Corp., a subsidiary of Arcos Corp., has opened a new plant in Philadelphia which substantially increases its production of stainless and low alloy steel submerged arc welding fluxes.

A. K. Allen Co., Inc., has moved to larger quarters at 255 E. 22nd St., Mineola, N. Y.

Haveg Industries has acquired **Lithgow Chemical Co.**

Sun Chemical Corp. has signed a contract to buy **Ansbacher-Siegle Corp.**

Societies

Porcelain Enamel Institute has elected the following 1958 officers: president—James W. Vicary, Ervite Corp.; vice presidents—A. S. Ault, Chicago Vitreous Corp.; J. F. Corkill, U. S. Borax & Chemical Corp.; W. H. Lowry, Vitreous Steel Products Co.; H. F. MacIntyre, Ferro Enameling Co.; J. McE. Patton, Ingram-Richardson Mfg. Co.; H. A. Ringelberg, Challenge Stamping & Porcelain Co.; R. N. Smith, Temco, Inc.; H. R. Spencer, Jr., Erie Enameling Co.; and J. C. Winget, Armco Steel Corp.; treasurer—P. B. McBridge, Porcelain Metals Corp.; chairman of the board of trustees—Glenn A. Hutt, Ferro Corp.; managing director and secretary—John C. Oliver.

Gray Iron Founders' Society has elected the following officers: president—J. Scott Parrish, Jr., Richmond Foundry and Mfg. Co., Inc.; vice president—A. M. Nutter, E. L. LeBaron Foundry Co.; secretary—A. H. Renfrow, Renfrow Foundry; and treasurer—C. R. Garland, W. O. Larson Foundry Co. New members of the board are: W. G. Butler, Golden Foundry Co., Inc.; R. Mayo Crawford, Turner & Seymour Mfg. Co.; J. Douglas James, Urick Foundry Co.; and R. W. Wilder, Elkhart Foundry and Machine Co.

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Meetings

SOCIETY OF AUTOMOTIVE ENGINEERS, annual meeting. Detroit. Jan 13-17.

MALLEABLE FOUNDERS' SOCIETY, semi-annual meeting. Cleveland. Jan 17.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, winter general meeting. New York City. Jan 20-24.

SOCIETY FOR APPLIED SPECTROSCOPY. Philadelphia. Jan 21.

AMERICAN SOCIETY OF HEATING AND AIR CONDITIONING ENGINEERS, 64th annual meeting. Pittsburgh. Jan 27-29.

SOCIETY OF PLASTICS ENGINEERS, 14th annual national technical conference. Detroit. Jan 28-31.

SOCIETY OF THE PLASTICS INDUSTRY, 13th Reinforced Plastics Div. conference. Chicago. Feb 4-6.

AMERICAN SOCIETY FOR TESTING MATERIALS, committee week. St. Louis. Feb 9-15.

AMERICAN INSTITUTE OF MINING, METALLURGICAL AND PETROLEUM ENGINEERS, INC., annual meeting. New York City. Feb 16-20.

INSTRUMENT SOCIETY OF AMERICA, eighth annual conference on instrumentation for the iron and steel industry. Pittsburgh. Mar 11-13.

AMERICAN ROCKET SOCIETY and AMERICAN SOCIETY OF MECHANICAL ENGINEERS, joint aviation conference. Dallas, Tex. Mar 17-20.

STEEL FOUNDERS' SOCIETY OF AMERICA, annual meeting. Chicago. Mar 17-18.

NATIONAL ASSN. OF CORROSION ENGINEERS, annual conference. San Francisco. Mar 17-21.

SOCIETY OF THE PLASTICS INDUSTRY, 15th annual Pacific Coast section conference. Palm Springs, Calif. Mar 26-28.

DESIGN ENGINEERING SHOW. International Amphitheatre, Chicago. Apr 14-17.

AMERICAN WELDING SOCIETY, welding show. St. Louis. Apr 14-18.

ELECTROCHEMICAL SOCIETY, spring meeting. New York City. Apr 27-May 1.

AMERICAN SOCIETY OF TOOL ENGINEERS, 26th annual meeting and tool show. Philadelphia. May 1-8.

AMERICAN ELECTROPLATERS' SOCIETY, annual convention. Cincinnati, Ohio. May 19-22.

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THE LAST WORD

by H. R. Clauser, *Editor*

Food and Poison for Engineers

With the need for engineers and scientists at an all-time high, we were taken aback by something that appeared in a recent folder advertising the books published by the University of Chicago Press. Prominently displayed among titles of highly scientific and engineering books was this item:

AND FOR YOUR WIFE—

Food Poisoning, by G. M. Dack

Fortunately, a short space below, a book entitled "Food for Life," by R. W. Gerard was listed. I presume they added this book to their list for those wives who do not care to poison their husbands.

The Pause That Kills

Sometime during your life you will have to make a speech, if you haven't done so already. So, I recommend to you a very helpful speech on speech-making for engineers. It was delivered by John Bateson of the Canadian Defense Research Board and reprinted by Tecnifax Corp., Holyoke, Mass. Mr. Bateson gives a lot of useful tips on how to organize your speech, how to deliver it, and how to use slides most effectively.

Most helpful and reassuring are his words about those seemingly long pauses when your tense mind is groping for the right word and you are threatened with panic. Although to you the pauses may seem alarmingly extended, he assures us that the audience seldom notices. This is because the speech-maker's mental activity tends to speed up, and thus time seems to pass more quickly for him than it actually does.

Rave Reviews for Selector

The initial appearance of the *Materials Selector* issue a few months back created the tense atmosphere of a Broadway opening night around the M/DE shop. The unspoken thought uppermost in all of our minds was, "What will they think of it?"

The reviews of the critics (you, our readers) are now in, and it looks as though we have a hit on our hands. A survey of reaction to the Selector showed that 56% of our readers rate it good and 37% rate it excellent. Perhaps more satisfying to us than even these high ratings are the comments received from over 200 subscribers. We appreciate their compliments as well as their helpful suggestions for making the next issue of the *Selector* (to be published in September) even more useful.

New Year Renovations

In going through this issue you may have noticed that we have made some changes in two of our regular departments. The Manufacturers' Literature department has been expanded to include, in addition to the reviews of suppliers' literature, book reviews and notes on recently issued reports. To more accurately describe the broadened scope of the department, we have renamed it Technical Literature (see p 77).

The second change is in our Prices and Supply department. The success of the "At A Glance" pages that start off our What's New in Materials department convinced us we should do the same for "P & S." So turn to page 183 for this new, fast reading feature that gives you up-to-date information on availability and prices of engineering materials.

Congressman Goes to 'School'

How can a congressman intelligently evaluate and vote on legislation that has many scientific and engineering aspects to it? Since virtually none of the legislators have technical training, they must rely heavily on the testimony of engineers and other expert witnesses. However, one congressman, Stuyvesant Wainwright (Rep., New York), has decided to find out for himself. He has embarked on a do-it-yourself, basic education course in engineering. He is making concentrated visits to plants in his district to bone up on technical matters. His first visit was to an electronics plant, Amperex Electronic Corp., where he learned about the design, production and materials pertaining to electronic equipment used in the missiles program.